

3D MENTAL VISUALIZATION IN ARCHITECTURAL DESIGN

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3D MENTAL VISUALIZATION IN ARCHITECTURAL DESIGN

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To My Family

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SUMMARY

Many architects report about mentally visualizing 3D aspects of their design ideas while simply working with 2D sketches of them. Indeed, in architecture, the general practice of conveying 3D building information by means of 2D drawings bears on the assumptions that every architect can mentally visualize a building in 3D by looking at its 2D drawings or sketches and that architects, as many report, can capture the 3D aspects of a building design during such 3D mental visualization practices. Additionally, many intuitively believe that the levels at which architects perform such 3D mental visualization practices is highly correlated to their spatial visualization abilities as defined by existing measures of spatial visualization ability.

This thesis presents the outcomes of protocol studies and analyses that were conducted with the aim of developing an in-depth understanding about such 3D mental visualization practices and capabilities of architects on the basis of four research questions. First, what might be the nature of the 3D mental visualization phenomena that architects claim to experience: what are the features of these 3D mental visualizations as evidenced in specific tasks; and what might be the nature of the mental representations created during these visualization processes? Second, can every architect carry out these 3D mental visualization practices; might there be individual differences among architects' performances? Third, might 3D mental visualization of buildings be only an architectural skill; can non-architects, who can read 2D architectural drawings, visualize a building in 3D based on its 2D drawings and can they do so to the same levels of performance of those of architects? Fourth, might performance in 3D mental visualization tasks be related to/predicted by spatial visualization ability? The major conclusions of this thesis with regard to the first research question include that (1) architects can be visualizing the buildings in one of the two major forms or by alternatively switching

between them: by imagining themselves situated within (almost) the actual size 3D building environment or by imagining a 3D small scale model of the building; (2) the mental representations they create during these visualization processes capture the various visual and spatial aspects of the buildings with a structure similar to that of an actual size or small scale model of the visualized space/form, yet the way they capture these aspects is not like the way these aspects would be captured from a certain viewpoint in reality; and (3) what they experience during these visualization processes is not like the continuous holistic visuospatial experience that one would have when looking at a building or walking inside/around a building. With regard to the second, third and fourth research questions this thesis concludes that (question 2) architects differ in their 3D mental visualization skills; (question 3) 3D mental visualization is an architectural skill in that it relies on certain abilities that become heightened in architects, possibly during education; and (question 4) 3D mental visualization skills are not related to spatial visualization ability as defined by the standard paper-folding test of spatial visualization ability.

CHAPTER 1

INTRODUCTION

“and where I should arrange... because it’s a house, where living areas should go, where master bedroom should go, that sort of thing... ummm...what I’m doing there is trying to visualize in my head in 3D what I’m doing... ummm like what’s in my head and what I’m trying to do... ummm...”

“I m just trying to imagine the view from the balcony upstairs of a sculpture garden below... so that’s why I was drawing like that... that’s just like balcony rails... so I’m just seeing flaming trees at the end... umm.. that’s when I was just trying to visualize in my head... drawing is not fantastic... but...”

‘Visualizing’ and ‘in 3D’, I suppose these two words are quite familiar to many of the architecture students and architects and also people who have been around them. Architects and students, like the architecture student who was making the above statements in the process of designing a house¹, most often report about mentally visualizing the various aspects of their design in 3D while simply generating or looking at 2D sketches of their design ideas. They talk about being able to visualize the 3D geometry of the spaces and forms, imagine how the various spaces in their design would appear if one were to walk through them, how the interior space would look like with different colors or under different lighting conditions, finish materials, and many others. They claim to be able to examine and reason about the various 3D spatial and visual aspects of the design ideas through such mental visualization practices.

¹ These statements are taken from a written transcript of a concurrent verbalization of an architecture student while designing a house as a part of an empirical study Yukhina (2007). Student while making the first statement was mainly looking at a sketch of the 2D layout of a house and while making the second was mainly looking at and adding to 2D sketch of the section view of the house.

Such 3D mental visualization practices are not unusual practices for architects; indeed, mentally visualizing a building in 3D based on its 2D drawings constitutes a cognitive component of the architectural design. In architectural design education and practice, 2D drawings constitute one of the major means for communicating 3D building information among the architects, students and instructors, through publications as well as the various parties involved in the design, construction and lifecycle of buildings. All these communications, at least on the architecture end, bear on architects and students having the capability to visualize and thereby apprehend the 3D layout and appearance of the presented building design simply by looking at 2D drawings or sketches of it.

Schools of architecture, most often starting from the first year of education, either through specialized courses or within the course of design studio, teach students how to generate and read 2D architectural drawings of a building, such as elevations, sections and plans, and how to develop 3D projection views of the buildings from these 2D drawings such as axonometric and perspective projections. Through this training, the schools aim and expect the students to not only develop the skills associated with reading and generating the 2D drawings but also to develop skills to mentally visualize the building spaces and forms in 3D based on their multiple 2D drawings.

So far, there has not been any research specifically targeting the 3D mental visualization practices or capabilities of architects. Indeed, in architectural design, there is scarcely any research on mental practices employed by architects or their capabilities in carrying out such mental practices. In architecture, there has been a general belief that spatial abilities play an important role in architectural design practices. Among these abilities particularly ‘spatial visualization ability’ (SVA), which can be defined as “the ability to manipulate or transform the image or spatial patterns into other arrangements”, has been believed to be a crucial ability for architects’ 3D mental visualization practices. In line with this belief, research carried out on the capabilities side has focused mainly on investigating the relationship between various spatial abilities, as measured by paper-

pencil tests, and design performance (Ho 2006; Yukhina 2007), learning styles (Yukhina 2007) or architecture students' spatial reasoning skills with 3D block arrangements (Akin 2003).

Ho (2006) in his study of architecture, industrial design and mechanical engineering students as a design group, found that there was a relationship between design studio grades and spatial visualization abilities in the female group but not in the male group and that there was no relationship between years of design education and the investigated set of spatial abilities which include spatial visualization and speeded rotation abilities. He further did not find a significant relationship between academic performance measured by the GPA and spatial visualization ability. Akin (2003) looked at architecture students' spatial reasoning skills with 3D arrangements of small rectangular blocks with students enrolled in all five years of an architecture school. He found that as they advance in their years of study, students of architecture become less efficient in their skills in manipulating small scale 3D rectangular blocks. Yukhina (2007) explored relationships between a wide span of spatial and visual abilities including spatial visualization ability as identified by paper pencil tests, and some aspects of the design outcomes (such as creativity, overall success, etc.) as investigated by a design task, academic achievement as measured by GPA, and learning styles. She found different distributions among the correlations between various spatial and visual abilities and academic achievement of first, third, fourth and fifth year students. Among these, she found a correlation between spatial visualization ability and academic performance in the first and third year students but not in the fourth and fifth year students. She also found fourth and fifth years students' visual and spatial abilities to be generally higher in different levels (some reaching statistical significance some not) than the first year students with spatial visualization ability not reaching to a statistical significance. In her investigation of the spatial visualization ability and design creativity, Yukhina (2007) found a correlation between them only in the third year students.

Overall, due to the differences in these findings with regard to the existence of a relationship between spatial abilities, particularly spatial visualization ability, and academic performance, design performance or the years in education, it has not been possible to derive at a conclusion in support of or against the widespread belief that spatial abilities play an important role in architectural design practices. In the meanwhile, these inconclusive results combined with my thinking about the various tasks in architectural design has led me to the intuition that various skills involved in architectural design might not be closely associated with the spatial abilities as measured by the paper pencil tests. Specifically, 3D mental visualization skills of architects, contrary to the general belief, might not be related to spatial visualization ability as customarily determined by paper pencil tests. Yet, given the scarcity of research on these capabilities, I have not elevated this intuition to a hypothesis.

Research studies conducted on the mental practices side has focused mainly on the role of mental imagery as a sole medium of design and/or how a design process carried out solely in imagery differs from that carried by sketching (Singh 1999; Bilda 2006). Both researchers, as a means to study the design conducted in imagery, carried out protocol studies where the designers had to generate design solutions to a given problem solely in their imaginations in a blindfolded condition and then generate quick sketches of their solutions. Singh (1999) looked at the design process of an architect in the blindfolded condition and characterized the imagination, or mental imagery, as a virtual design studio in which the designer conceived the 3D building in his mind's eye and shaped it through the design process. Bilda (2006) analyzed the protocols obtained from six architects' design processes under blindfolded and sketching conditions with a variety of categories, by interpreting to which of the categories the content of the statements pertain. These categories included the quality of design outcomes, idea generation, and rate of cognitive activity associated with functional, conceptual and perceptual actions. Significantly, he found that the design outcomes were similar under both conditions.

There were no significant differences in cognitive activities, which he took to suggest that the designers carried out a design solely in imagery with almost in the same quality and through similar cognitive processes as they did through sketching. He concluded that imagery can be a very efficient and productive medium for design. Overall, these studies indicated that architects can design solely in their imaginations, deal with various aspects of design in 2D and 3D, and manipulate their designs in their minds to come up with satisfying design solutions.

Finally, in addition to the literature above, some researchers in design cognition have emphasized interactive involvement of visual mental images in the kind of visual reasoning that occurs during sketching activities of designers (e.g. Schön 1987; Goldschmidt 1991; Schön and Wiggins 1992; Suwa and Tversky 1997; Kavakli and Gero 2001). In these interactions, visual images are argued to inform creation of sketches and support interpretation of the sketches in new ways, which can then give access to other visual images and enable regeneration of the design ideas in the sketches.

In sum, the studies in the existing architecture literature that have focused on mental imagery and spatial abilities of design from various perspectives, have not contributed much to our understanding about the 3D mental visualization practices and capabilities of architects. Imagery studies have showed that architects can design in imagination and have suggested that architects can create 3D images in their minds but did not provide an understanding about what the natures of these so-called 3D images might be or how the building information might be rendered in them? On the basis of the findings from spatial ability studies, it has not been possible to derive a coherent understanding about the role and improvement of spatial abilities in architectural design in general or the spatial visualization abilities in 3D mental visualization practices in particular.

Overall, what we currently know about 3D mental visualization in architecture are that (1) communication of building information through 2D drawings in architectural

design bears on the 3D mental visualization practices, (2) architects, during such practices, appear somehow to be capturing the 3D appearance of the building designs in their minds, (3) many architects claim to carry out such 3D mental visualization practices during design and think that they benefit from these practices in thinking about the 3D aspects of their designs, and (4) many believe that these practices highly rely on spatial visualization abilities. But, we do not actually know what is it that architects create in their minds while carrying out these practices. What is the nature of the mental representations they create? What kinds of information do they really capture in these representations? Thus, we do not really know what 3D aspects of a building design are being conveyed through its 2D drawings within the various educational and professional contexts in architecture or in what ways architects might be benefiting from these practices in their design thinking processes. Furthermore, we do not even know whether every architect, as is generally expected, can mentally visualize a building in 3D based on its 2D drawings; whether such skills develop or become heightened in architects in the context of their educations and practices; or whether these skills, as many intuitively believe, highly rely on spatial visualization abilities.

This thesis presents a research study which was conducted with the aim of developing an in-depth understanding about the 3D mental visualization practices and capabilities of architects on the basis of four major research questions that follow.

- (1) What is the nature of the 3D mental visualization phenomenon architects claim to experience when imagining a building space/form or walking inside/outside a building?
 - a. What are the features of these 3D mental visualizations as evidenced in specific tasks?
 - b. What might be the nature of the mental representations that are created during these visualization processes?

- (2) Can every architect mentally visualize a building in 3D based on its 2D drawings; might there be individual differences among architects in their 3D mental visualization performances?
- (3) Might 3D mental visualization of buildings be only an architectural skill?
 - c. Can non-architects, who can read 2D architectural drawings, visualize a building in 3D based on its 2D drawings?
 - d. Can they do so to the same levels of performance as those of architects?
- (4) Might performance in 3D mental visualization be related to/predicted by SVA?

This thesis is organized into 7 Chapters. The second chapter presents the research design of a 3D mental visualization study conducted with the architects and non architects to address the research questions formulated here. It describes the design of the study and the various analyses conducted on the data collected in this study. The chapters 3, 4, 5 and 6 presents the outcomes obtained from these analyses. Chapter 3 outlines and presents the results of the analysis that was conducted with the aim to identify the participants' 3D mental visualization performances. Chapter 4 presents and discusses the results of the statistical analyses which were conducted to address the 2nd, 3rd and 4th research questions. Chapter 5 discusses the outcomes of the analysis conducted on the visualization protocols of the architecture participants in this study with the aim to elucidate the 1st research question. Chapter 6 outlines and presents the outcomes of the analyses that were conducted on the various drawings that architecture participants generated in this study with the aim to address the second part of the 1st research question. Chapter 7 discusses the findings of this research and their implication for architectural education and practice and cognitive science research. Chapter 8 concludes by summarizing the research study, discussing limitations of the research and future research.

CHAPTER 2

RESEARCH DESIGN AND METHODS

This chapter presents the research design of a 3D mental visualization study conducted with the architects and non architects to address the research questions formulated in Chapter 1. It is organized in two major sections. The first section discusses the design of the study including the selection of the participants, the materials, and the procedure. The second section outlines the various analyses conducted on the different types of data collected in this study.

2.1 The Study

The study was conducted with a total of 21 participants including 14 graduate level students in architecture and 7 graduate level students or researchers in mechanical engineering. In the selection of the architecture participants, the decisive factor was the participants' having a Bachelor of Architecture degree or a Bachelor of Science degree in Architecture. For the selection of mechanical engineering participants, the decisive factors for inclusion in the study were (1) the participant's having received an undergraduate degree in mechanical engineering or currently studying mechanical engineering at the graduate level while holding an engineering undergraduate degree with a specialization in mechanical engineering and (2) the participant's having not dealt with design of building systems. The educational profiles of the participants are outlined in Table 1.

The participants in this study were recruited through word of mouth. The architecture participants were mainly recruited by visiting the graduate level studios and research laboratories and randomly approaching to the individuals to talk about the study. The mechanical engineering participants were recruited by (1) visiting the research labs

in mechanical engineering and randomly approaching the individuals to talk about the study and (2) by finding out the e-mail contacts of the graduate research assistants and sending them e-mails about the study. Each of the approached or contacted individuals was first asked about their educational background in order to find out whether they met the conditions required for inclusion in this study; in case they did, they were then asked if they would like to take part in this study.

In this study there were two major considerations that led to selection of mechanical engineers as the non architects. The first was their not having difficulty to read the building information from the 2D drawings. Normally lay people would not be able or would have difficulty to read the 3D building information from the 2D architectural drawings of the building. On the other hand, students from various design fields which deal with design of 3D entities such as mechanical engineering, industrial design or civil engineering and where 2D projection drawings are used to represent these 3D entities would possibly be able to read the 2D architectural drawings of a building without much difficulty; this assumption was proven valid as all the mechanical engineering participants did not have difficulty reading the 2D drawings of the buildings in this study. Yet, designers from these other fields of design, also carry out mental visualization practices where they mentally visualize the 3D entities based on their multiple 2D projection views such as side and top and cross sectional views. Indeed, like the architecture students, students in these fields are expected to develop such visualization skills in the course of their graphical drawing courses where they learn to generate 2D projection views of the 3D entities. One of the objectives of this study was to investigate whether non architects can mentally visualize a building in 3D and whether they could do so in the same extent as architects can do, the selected group of non architects' should not be acquainted with working with 2D drawings of a building and carrying out the kinds of architectural visualization tasks that would be investigated in this study. Since the architecture and industrial design students in Georgia Institute of

Technology took a common design studio in their first years of study and deal with representation and design of entities from both fields, it would not be reasonable to select industrial design students as a representative of non-architects in this study. Yet, it was possible for the mechanical engineers to be acquainted with architectural drawings and architectural visualization tasks in case they are specialized in an area dealing with building systems design. This is why, in selection of mechanical engineers their not being acquainted with design of building systems was established as a decisive factor.

This study was conducted with one participant at a time in two consecutive sessions that were scheduled based on the participant's available times. In the first session the participants carried out the 3D mental visualization part, which had five subsections to it. Time taken by the participants to complete this session varied from 1 hour and 18 minutes to 3 hours and 8 minutes with a total of 45 hours and 18 minutes. In the second session, the participants first took a paper pencil test of spatial visualization ability and then generated a perspective drawing of an actual building space. The time taken by the participants to complete this session of the study varied between 20 minutes to 55 minutes with a total of 10 hour and 3 minutes; within this total 6 hours and 33 minutes was spent in their department buildings. The rest of this section describes the structure of each part of the study in detail including the materials and the procedure and underlying motivations and considerations.

2.1.1 The 3D Mental Visualization Part: Structure, Materials, and Procedure

The 3D mental visualization part of this study was composed of five sections carried out consecutively in one session in the following order: (1) a background questionnaire in which participant responded to questions about educational background and work experience, (2) a pre-study interview in which participant was interviewed about their employment of 3D visualization practices during design, (3) recall tasks in which the participant was asked to imagine the appearance of an interior space and

exterior form of a familiar building that is learnt by experience from given locations (4) 3D mental visualization tasks in which the participant was required to imagine the 3D appearance of the interior space and exterior form of two building designs respectively from the given locations and when walking inside/around the building based on their multiple 2D drawings and (5) a post-study interview in which the participant was interviewed about their 3D mental visualization experiences in this study.

This part of the study was conducted in a silent room with a table and chairs. The participant was provided with drawing materials such as sketching paper, pencils, pens, rulers, and so on. The time taken by each participant to complete this part varied between one and a half to three hours, depending on the time the participant took to study the materials and respond. The entire session was documented by a video recorder for the collection of visual and verbal data. Prior to starting the tasks, the IRB form was discussed with the participants and signed by them.

To meet its objectives, the study had to ensure that the participants did not have any familiarity with the two building designs that they would be required to visualize based on their 2D drawings in the context of the 3D mental visualization tasks. This was why, before proceeding with this part of the study, the participants were first presented with the name of the building designs that they would be required to visualize in this study and name of the designers of these building and asked if they had seen the buildings or any drawings or images of these buildings. Then they were provided with the 2D drawings of the buildings (as prepared for this study) and asked once again if they had any familiarity with these buildings. If the participant reported having no familiarity, the study would be carried out with that participant, which turned out to be the case for all the participants who volunteered for the study. If the participants had reported any familiarity with the building designs, they would have been excluded from the study, given the reason for being excluded, and received the same compensation as those who continued the study.

This part of the study was conducted with mechanical engineering and architecture participants following the same procedure and utilizing the same materials except for two minor differences. The first was an extra step that the mechanical engineering participants had to take part in. Before beginning the procedure, they were shown a sample architectural drawing which involves the symbols and conventions in the drawings that they would see in this part of the study. They were first asked to look at and read the sample drawings and ask about any symbol that they could not interpret in the drawing. The purpose of this session was to determine if the mechanical engineering participants would be able to read the architectural drawings and to introduce them to any conventions or symbols that they were not familiar with. The second difference between the procedures followed by architecture and mechanical engineering participants was in the focus and depth of the pre-study interview, which will be described in Section 2 below.

Section 1- Background Questionnaire:

In the first section of this part of the study, the participants were verbally questioned about their educational and professional background. The information gathered on the participants' educational background included what their undergraduate degree was in, in which year they had graduated from the university, whether they had received their degree from a university in a foreign country, what their current graduate program of study was, and whether they had any other undergraduate or graduate degrees. Regarding the professional backgrounds, the participants were asked to provide information about any work experience they had had in the field, how long they had had this work experience, the responsibilities they had been assigned at work such as whether they had worked in design, drafting, construction, and so forth, and the last time that they had carried out a design project. The background information collected from the answers to this questionnaire is presented in Table 1, and the questions are listed in Appendix 1.

Table 1 Participants' background data

	Undergraduate study			Current program of study		Years of Prof. Exp.		Last Design	Other degrees
P #	Degree	Country	Year	Major	Year Start.	Work	Teach		
A1	B.Arch.	Foreign	1997	PhD Arch.	2002	5	3 (C)	current	M. Community Planning
A2	B.Arch.	Foreign	2002	PhD Arch.	2006	4	0	2007	no
A3	B.Arch.	Foreign	2002	PhD Arch.	2006	2.5	0.5 (C)	2005	M. Arch
A4	B.Arch.	Foreign	1998	PhD Arch.	2006	8	0	2005	M. City Planning
A5	B.Arch.	Foreign	2006	Adv. S. Arch.	2008	0	0	current	M.S. Arch B.S.ME
A6	B.Arch.	Foreign	2007	M.S.B.T.	2008	0.5	0	2007	no
A7	B.Arch.	Foreign	2000	PhD Arch.	2006	5 (PT)	5	2005?	no
A8	B.S. Arch.	USA	2006	M. Arch	2008	2.5	0	current	Assoc. Math
A9	B.S. Arch.	USA	2003	M. Arch	2007	5	0	current	no
A10	B.Arch.	Foreign	2003	PhD Arch.	2008	6 (PT)	5	2008	no
A11	B.Arch.	Foreign	1996	PhD Arch.	2007	7 (PT)	9	current	no
A12	B.Arch.	Foreign	2001	PhD Arch.	2005	0	1.5 (C)	2001	M.S. Arch
A13	B.Arch.	Foreign	2005	M.S.B.T.	2008	1	0	2007	no
M1	B.S.M.E	Foreign	2008	PhD M.E	2008	0	0	current	no
M2	B.S.P.E	Foreign	2005	PhD M.E	2007	0.5	0	current	M.S.ME
M3	B.S.M.E	USA	2005	PhD M.E	2007	1 (PT)	0	current	M.S.ME
M4	B.S.M.E	USA	2000	PhD M.E	2000	0.75	0	2004	no
M5	B.S.G.E	USA	2007	PhD M.E	2008	0.5	0	2007	no
M6	B.S.M.E	USA	2007	M.S.M.E	2007	1	0	2007	no
M7	B.S.M.E	Foreign	2008	M.S.E.E	2008	0	0	current	no
List of abbreviations: A: architecture participant ; M: mechanical engineering participant; PT: part time; C: current ; B. Arch: Bachelors degree in Architecture, B.S. Arch: Bachelor of Science in Architecture, B.S.M.E: Bachelor of Science in Mechanical Engineering, B.S.P.E: Bachelor of Science in Product Engineering, B.S.G.E: Bachelor of Science in General Engineering; PhD. Arch: Doctor of Philosophy in Architecture, PhD. ME: Doctor of Philosophy in Mechanical Engineering ; M. Arch: Master of Architecture, M.S.B.T: Master of Science in Building Technology, Adv. S. Arch: Advanced Studies in Architecture, M.S.M.E: Master of Science in Mechanical Engineering, M.S.E.E: Master of Science in Electrical Engineering; M.S. Arch: Master of Science in Architecture									

As this study was conducted with graduate students, it was very likely that some participants had professional work experience and had thus been engaged in more design projects after graduation from the university. It was also possible that some participants were involved in a design studio project at the time this study was conducted whereas some had not participated in the activity of designing for some period of time. These situations might have had an effect on the 3D mental visualization performance of the participants. The motivation behind gathering information about participants' professional experience and their last engagement in a design project was to be able to explore whether such differences could be a source of any possible differences in 3D mental visualization performances in case such differences are found. Through such an exploration we could gain insights on whether such 3D mental visualization skills might be situated in after graduation practices or architectural design education in case the outcomes in this study suggests that such skills could be conditioned in architectural design practice.

Section 2- Pre-Study Interview

The background questionnaire was followed by a short interview. The interview was structured slightly differently for architecture and mechanical engineering participants. For the architecture participants, the aim was to gain insight on two issues: (1) the participants' use of 3D mental visualization practices in their design process and (2) the participants' skills in visualizing the 3D composition of a building design based on its 2D drawings. This information might provide us with various insights into the interpretation of the study results. For instance, we could logically expect a participant, who generally has difficulty in visualizing a building design based on its drawings, to perform poorly on the 3D mental visualization tasks involved in the study. Likewise, a participant could have reported not carrying mental visualization practices during design but rather using external visualization tools for exploring 3D aspects of the design. For

the mechanical engineering participants, the aim was to gain insights on two issues (1) whether the participants were familiar with orthographic drawing techniques, and (2) whether they employ 3D mental visualization practices in the design process.

The interview was structured as a semi-structured interview focusing on the above issues and evolving based on the responses of a participant. It followed a guiding framework established prior to the study. This framework consisted of a list of the two issues under consideration with possible question forms and further questions that might be prompted depending on how they responded to the initial question. In the interview the architecture participants, were first asked to tell how they generally worked out the 3D aspects of their design ideas in the design process. The intention of formulating the question this way rather than directly asking participants whether they employed 3D mental visualization practices during design was to encourage the participants to describe the design process from their perspectives—with regard to how they think that they deal with 3D aspects of design; in this way, it would be possible to gain further insights into not only the mental visualization practices that they used but also other practices that they utilized in support of or in place of mental visualization such as using 3D modeling tools or physical models. The next questions to be asked of the architecture participants were mainly identified based on their responses to the first question. Some participants in response to the first question did not ponder on the issue of whether they employ 3D mental visualization practices during design and were accordingly asked some additional questions to gain insights about issue before moving to the second issue. Whereas the participants who pondered on this issue were directly asked about the second issue aimed to be addressed in this interview i.e. whether they thought they could interpret the form and spaces of a building in 3D by looking at the 2D drawings of the building and if so, how they did it. In the interview with mechanical engineering participants, they were first asked about their familiarity with orthographic drawing techniques such as the representation of a 3D object by generating multiple views-sections, plans, and

elevations. Then, as in the case with architecture participants, they were asked about how they deal with the 3D aspects in their design processes and they were also directed further questions for elucidation depending on their responses. The set of issues and alternative phrasing of the questions defined in the interview framework as a guideline are listed in Appendix 1.

Section 3- Recall Tasks

Following the pre-interview, participants were asked to carry out two recall tasks that involved (1) imagining the appearance of an interior space and the exterior form of a familiar building that they had learned by experience from locations specified by the experimenter based on their memories of that building space and form, (2) concurrently describing their imaginations and (3) generating a drawing of the imagined appearance of the recalled building space (RBS) from that given location just after their verbal descriptions of it.

As will be discussed in the perspective drawing task section of the study, the participants in the second section of the study would be requested to draw RBS by going there and actually looking at it from the same location specified in this recall task. This was why, the familiar buildings that the participants imagined in these tasks needed to be buildings on campus to which the participant and experimenter can walk together to do the task on site. To meet this requirement, the participants were first asked if they were quite familiar with their department or office buildings on campus and whether they could recall the main interior space such as the gallery space and the exterior appearance of these buildings. If they were not, they would be asked about another campus building that they were more familiar with.

The procedure followed in the recall tasks can be summarized as follows:

- Mechanical engineering participants were first asked about their office/department buildings. Then they were asked whether they were familiar

with the office/department buildings that they mentioned. In case they were, they would be asked whether they could recall it from the exterior and the interior. In case they were not familiar with those buildings, they would be asked whether they were more familiar with another building on campus.

- Architecture participants were first asked about their familiarity with the West Architecture Building, if they had carried out a project on and worked with 2D drawings of this building; none of them had done so. But, in case they had, they would have been asked to recall another familiar building on campus.
- Once the familiar building was defined, the participants were told a location inside the building and were then asked to imagine themselves standing in a given particular location and looking at the space from in a particular orientation and imagine and describe the appearance of the space in as much detail as possible.
- After the description, participants were requested to sketch the imagined appearance of the RBS with no instructions or specifications as to which drawing type (e.g., isometric or perspective) they were to use; yet, in case they asked they would be requested to depict the space in perspective as would be seen from the given location.
- After the participants completed the drawing, they were told a location outside the building and requested to imagine themselves at that location, looking towards the building, imagine and to describe the appearance of the building from their current location in as much detail as possible.
- At the end, the participants were informed that they would be required to carry out similar tasks in the following section of the study but that they would be required to imagine the 3D appearance of unknown buildings by studying their 2D drawings.

The motivation behind having participants recall and imagine the appearance of a familiar 3D building space and form from specified locations and draw a perspective view of it was twofold. First, this would familiarize the participant with the activity of imagining the 3D appearance of a building space and form from a location given on the spot, concurrently describing it and then generating a drawing of it. In the following section of the study, they would be required to carry out a similar activity where they would be imagining the 3D appearance of the building spaces/form by studying the 2D drawings of the buildings. Second, as will be discussed in analyses of the drawings having these participants' drawings of the RBS and the participants' drawings of the mentally visualized building space/form based on their 2D drawings, it would be possible to explore whether there are some similarities in these drawings.

Section 4- 3D Mental Visualization Tasks

After the recall tasks, the participants were asked to perform a number of 3D mental visualization tasks that mainly involved visualizing a building's (Building 1) interior spaces i.e. interior visualization tasks and visualizing another building's exterior form (Building 2) i.e. exterior visualization tasks. In this session, they were given the 2D drawings of one building at a time and requested to study these drawings for 10 minutes and visualize the interior spaces of the Building 1 (B1) and the exterior appearance of Building 2 (B2) by imagining themselves walking inside B1 and around B2 respectively. After the study session the drawings were removed and the participants were required to visualize and describe the appearance of interior space of B1 and exterior form of B2 by imagining themselves walking and by imagining themselves at spontaneously specified locations inside B1 and outside B2. They were also required to draw some of their mental visualizations of the building space/form from the specified locations upon completing their verbal descriptions.

The 3D mental visualization tasks in this study were adapted from a mundane activity that architects carry out in the course of their daily practices (i.e., visualizing/interpreting 3D composition of building components and spaces based on their multiple 2D drawings such as plan, section, or elevation drawings). In the design of the tasks, a primary concern in the selection of the 2D views given to the participants was to provide them with all the necessary information for inferring the 3D geometry of the interior spaces /the exterior form of the building; but not to provide the 2D elevation or section views which by itself or in combination with the others would constitute the interior or exterior elevations of the building space/form that would be seen from the locations specified on the spot. The source of this concern was that participants, in their verbal descriptions of a space or a portion of a buildings' exterior composition, might define various elements in a 3D scene mainly by recalling series of 2D elevation views of that interior space or that portion of the exterior composition of the building one 2D view at a time rather than integrating information from multiple drawings and trying to construct a 3D visualization of the space. Similarly, one might develop a drawing of a 3D space/form, albeit not a very legitimate one, by first drawing the frontal view as recalled from one elevation view and then integrating the elevations of the other side(s) rather than imagining the 3D appearance of the scene. For instance, when asked to describe the exterior appearance of B2 from the southwest corner, depicted in Figure 1 (or similarly, the appearance of the building from various sides when walking around it), the participant, if provided all the elevation views of the building, could basically define the components seen on each side of the building by recalling the 2D elevation drawings of the building. On the other hand, they would not be able to do so if the section drawings depicted in Figure 1 were given to them for B2, and would need to employ 3D composition strategies to derive the exterior appearance of the building from different sides. Overall, to discourage the use of such 2D view-based strategies and to encourage 3D visualization strategies as much as possible, participants were not given a full set of

2D drawings with all possible sections and elevation drawings of the buildings; they were given a minimum number of section drawings taken from critical section lines. From these drawings they could derive the height information of almost all the components² and combine it with the information provided in the plan drawings to derive the 3D geometry of the components and the spaces.

Two building designs that would be visualized in the interior and exterior visualization tasks based on their 2D drawings were adapted from, Paul Rudolph's Hirsch House (Rudolph, P., S. Moholy-Nagy et al. 1970; Pearson and Hine 1996) and Charles Gwathmey's Gwathmey Residence (Breslow and Breslow 1977; Collins 2000) respectively. As noted previously, it had been determined in advance that the participants were not familiar with these buildings. The 2D drawings of these buildings were prepared by developing 3D computer models and generating 2D projection views from them. These building designs were selected by reviewing the various house designs available in the publications. In the selection of the building for the interior visualization task, the main considerations were that (1) the house would embody a gallery space that would continue at multiple levels and be surrounded by multiple elements located at different levels or parts of the space, and (2) the building would not be a large-scale, complex building in terms of the number of functions and spaces housed on each floor level. In the selection of the building for the exterior visualization task, the main considerations were that (1) the house would have a fragmented exterior composition embodying voids and

² In B1, the section drawings did not provide the exact height information of three elements -half level platforms inside the living room space- which could approximately be inferred from the height between the two floors and the number of steps in the stairs that connect them to the two levels. In B2, the section drawings did not contain the height information of two windows. The missing height information for these elements was compensated for in the evaluation of the participants' drawings of their 3D mental visualizations by excluding their geometry from consideration. For the elements in B1, whose height information could be approximately inferred, the participants were informed about their height information while reading the drawings, as discussed in the following experiment.

solids with different geometries, and (2) the house would be a self-standing house (open on four sides) without a complex interior layout/organization of spaces.

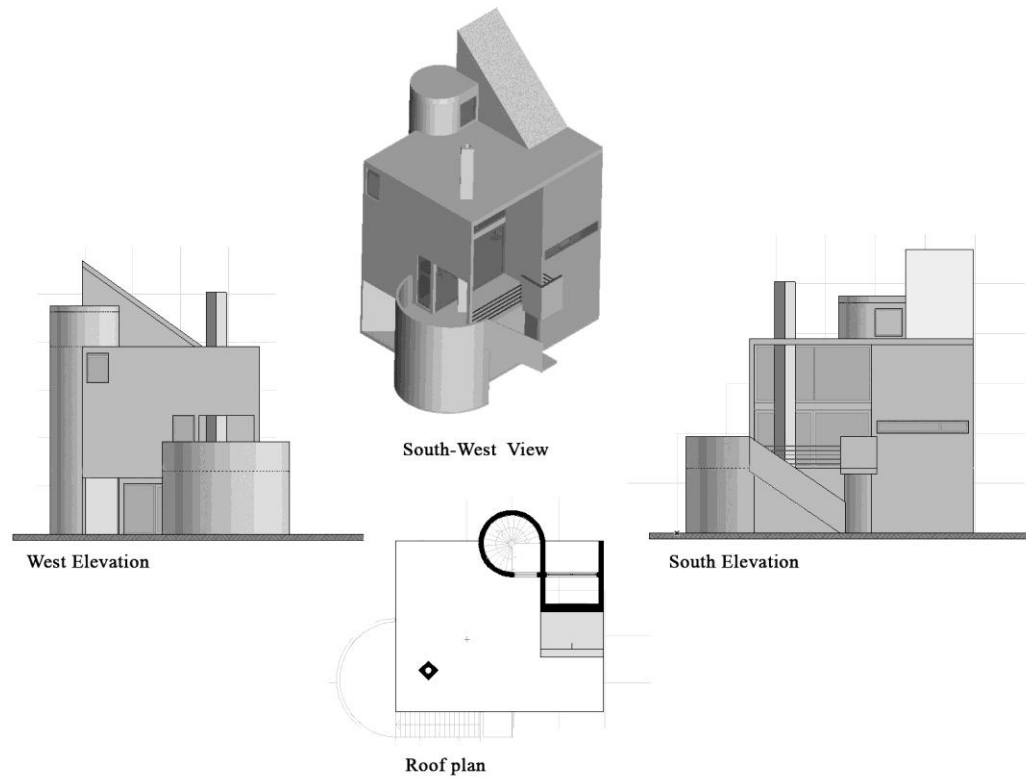


Figure 1 3D projection view of a building from southwest and 2D drawings of the building facades that are visible in this view

Procedure:

The procedure followed in this section of the study and the underlying considerations in certain steps can be summarized as follows:

- The participants were given a written description of the 3D mental visualization tasks and the procedure to be followed³. The description, which was also read aloud to the participants, follows:

In this section, you will be the given plans and section drawings of 2 house designs one at a time. You will be required to study the 2D drawings of each building in order to visualize and learn the appearance of building spaces and forms in 3 dimensions in as much as detail as possible during a 10 minute study session.

In visualizing the given house designs, you will be required to visualize the first house design from the interior and the second house design from the exterior.

In visualizing the first house design from the interior:

You are required to study the building's drawings to visualize what you would be seeing in 3D if you were to be walking through the building's various interior spaces and looking around to examine the appearance of these spaces and the elements within.

After the study session, you will be required to

(1) Describe to the experimenter what you would be seeing in 3 dimensions (in terms of the elements and their forms) within the surrounding spaces while walking through the spaces inside the building.

(2) Describe what you would be seeing in 3 dimensions from two different locations inside the building; these locations will be specified by the experimenter.

(3) Generate a drawing of one or more of the described views of the building on paper.

³ The complete task description, including the procedure in the format provided to the participant, can be viewed in Appendix 1.

In visualizing the second house design from the exterior:

You are required study the drawings of the house to visualize how the building would appear from the exterior from different directions if you were to walk around it and looking at it to examine the appearance of the building form and elements.

After the study session you will be required to

(1) Describe to the experimenter the form and elements of the building that you would be seeing in 3D from a particular location outside the building provided by the experimenter.

(2) Describe what you would be seeing in 3D while walking around the building.

(3) Generate a drawing of one or more of the described views of the building on paper.

- The participants were given 2D drawings of B1 Figure 2 and required to read the drawings aloud. They were informed, while reading aloud, that they could ask the experimenter about any symbol or part that they could not read or infer from the drawings. The motivation behind the read-aloud session was to familiarize participants with the drawings and the overall layout of the building and to be able to provide them assistance with reading the drawings if they needed it. In this read-aloud process, the participants were also provided with the height information of three elements whose exact height information was not available in the drawings.
- After reading aloud, participants were given ten minutes to mentally visualize B1 from the interior by studying the drawings without using any paper and pencil.

- After the ten minutes, participants were asked whether they needed additional time to study, and if so, they took the time needed until they were ready to proceed.
- As the participants completed the study session, the drawings of the building were collected back and the participants were asked the questions that follow.
- Can you walk me through the building's interior spaces by describing what you are seeing in 3D within the surrounding spaces as you walk through them in as much as detail as possible? The participant was not told a starting point, the purpose of which was to find out whether the participant had identified a certain starting point and a navigation path in their imagination of the building during the study session. In case participant inquired about a starting point, they would be told to start from the main entry.)
- From your current location (the last location described in the walkthrough), can you walk back to the second floor living space/balcony area? The purpose of this additional question was to see how the participant would respond to it: whether they would imagine walking back and concurrently describe the appearance of the surroundings that they had already described from the reverse direction or not. In case the participant simply answered "yes" without describing a walk, they would then be asked the following question as below; likewise, in case the participants did not say anything at all, in essence, waiting for a following query, they would also be asked the following question.

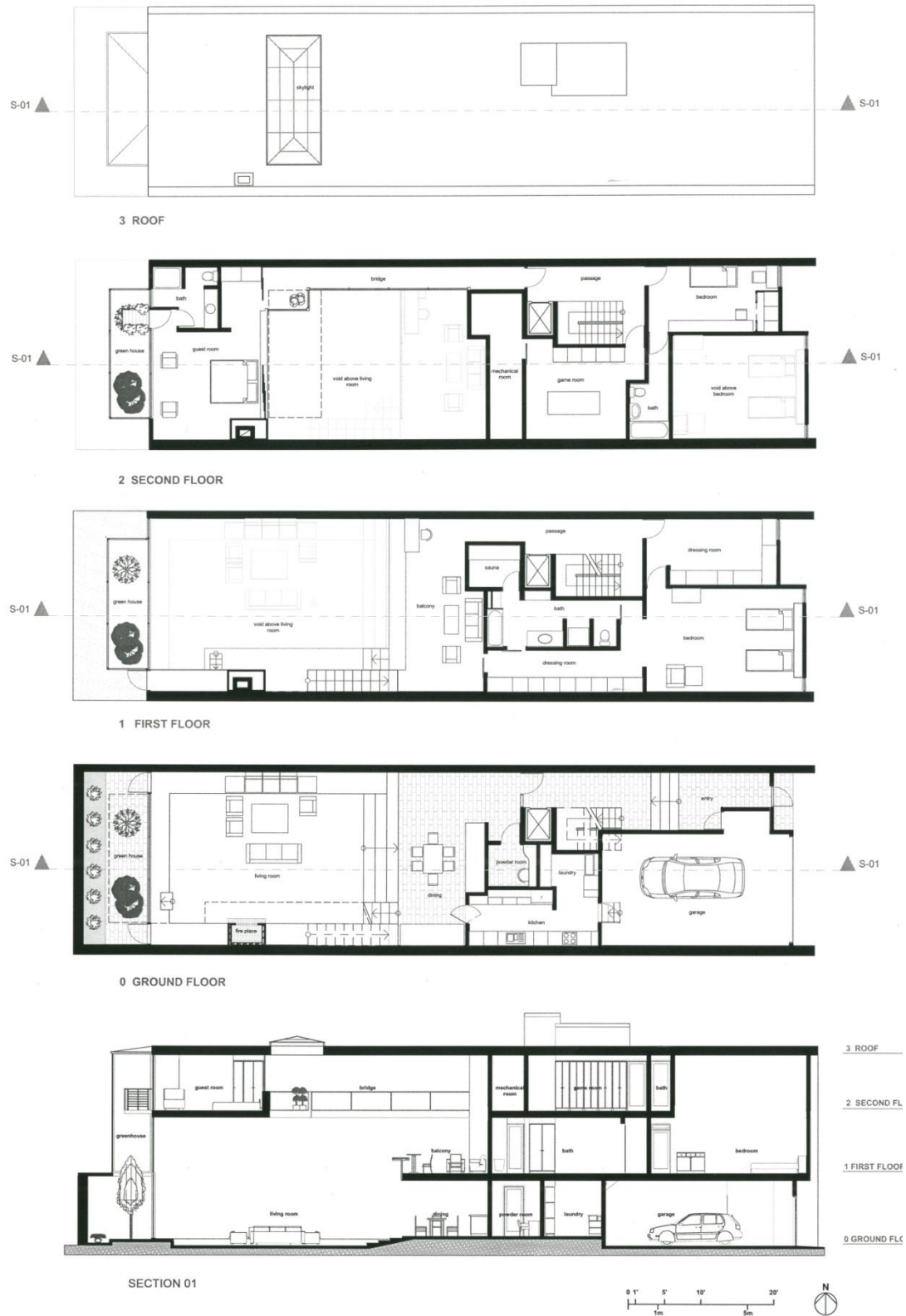


Figure 2 Drawings of B1

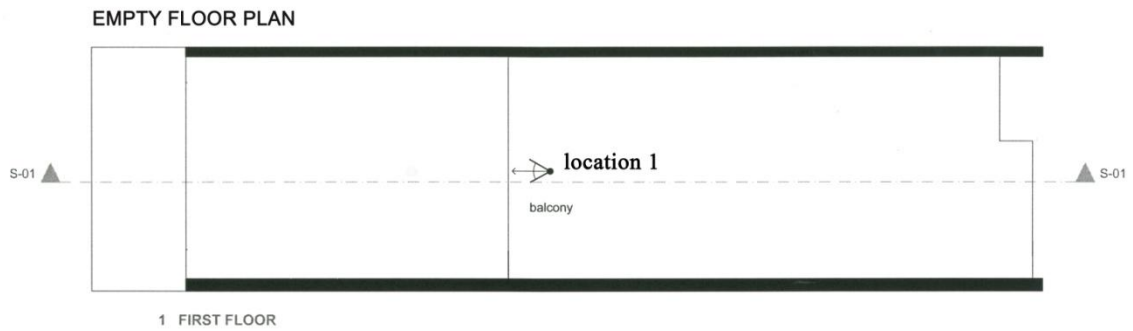


Figure 3 Location 1 at the first floor of B1

- Can you now imagine yourself standing at this location on the first floor living space/balcony area (the participant was shown Location 1 on an empty floor plan as in Figure 3)? Describe to me what you see ahead of you from this location looking towards this direction (as indicated by the arrow) in as much as detail as possible?
- For the purposes of a further study, after the participants completed their descriptions, they were asked some further questions including: As you are standing there, can you describe to me what you see if you turn to your right/90 degrees to your right; if you turn one more time to your right/your back from our original direction; if you turn one more time to your right/your left from your original location; when you look up/what is above you? As carried out for future research, these portions of the participants' visualization protocols were not included in the analyses that are conducted in this research.
- Can you imagine yourself standing in front of the greenhouse on the ground floor (the participant was shown location 2 on an empty floor plan, as in Figure 4) and describe to me what you see ahead of you from this location looking towards this direction (as indicated by the arrow) in as much as detail as possible?

- Can you now draw what you see from there (the location 2)? Here, the participant received no specification as to a drawing type (such as isometric or perspective projection) In case they asked, they would be told to draw a perspective drawing of the space from the given location if they could.

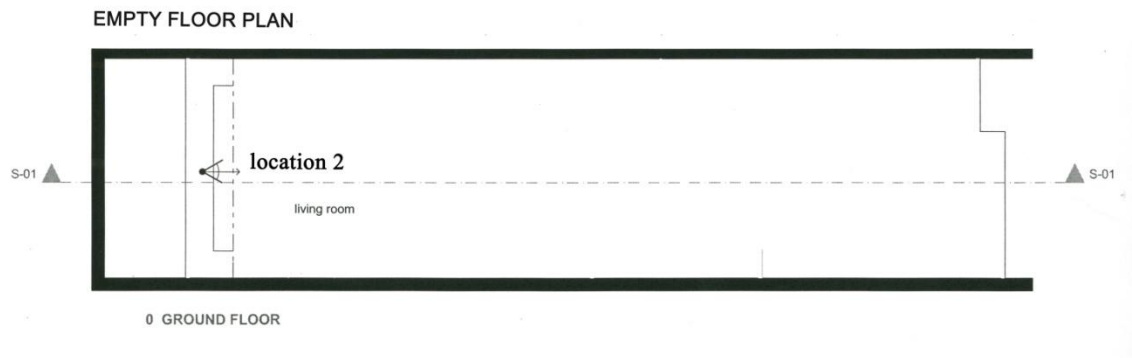


Figure 4 Location 2 at the ground floor of B1

- After the participant responded to queries, they were asked if they wanted to take break. If they did not, or after they took a break, they received 2D drawings of B2 (Figure 5). Then the procedure described for B1 above was repeated. However, this time, the participant was required to mentally visualize B2 from the exterior. After completion of the study session and collection of the drawings, the participant was asked the following questions in the order presented here:

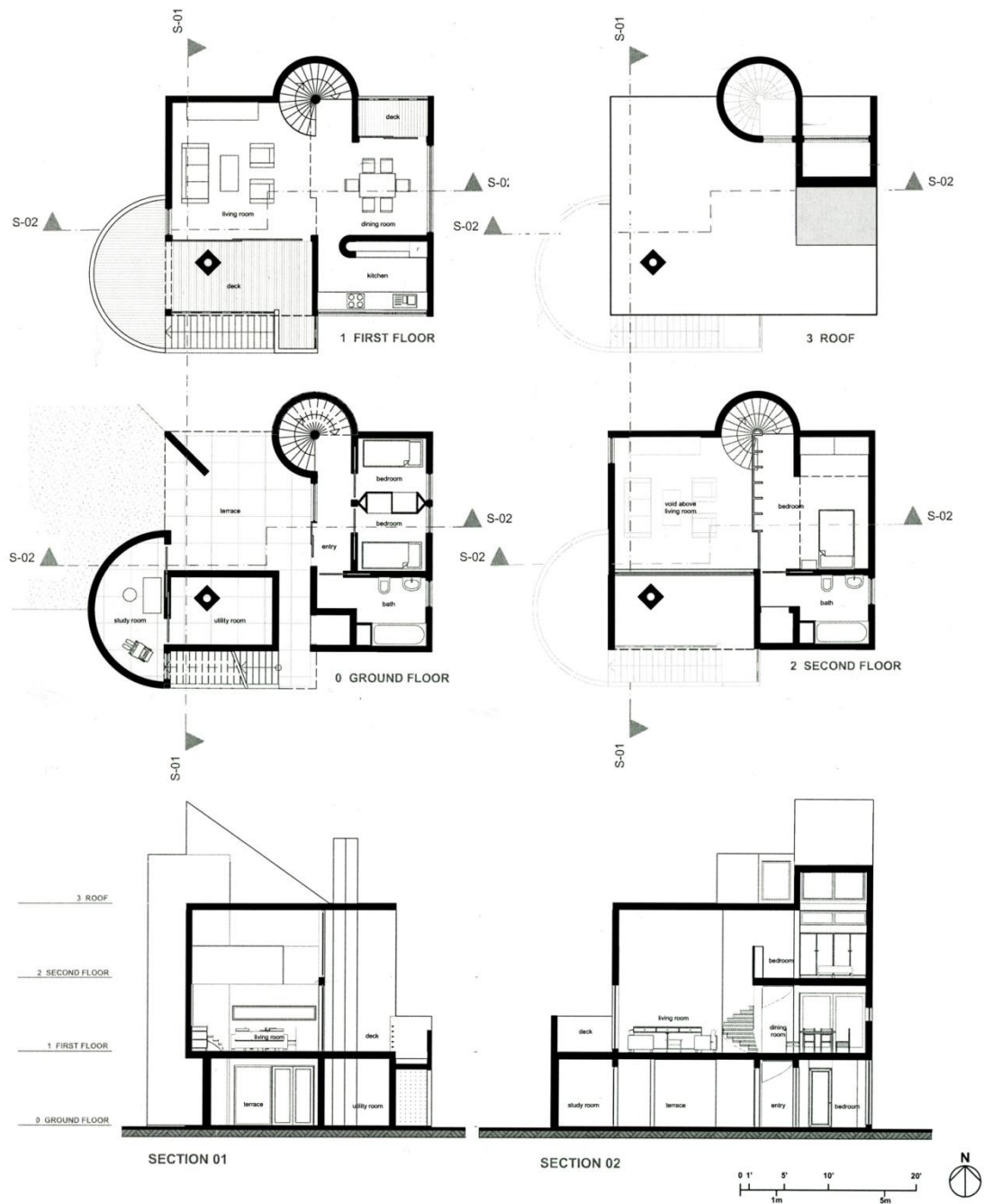


Figure 5 Drawings of B2

- Can you imagine yourself standing 30 feet (around 9 meters) away from the southwest corner of the building (the participant was shown the location on an empty floor plan as in Figure 6) and looking towards the building? Describe what you see from there in 3 dimensions?

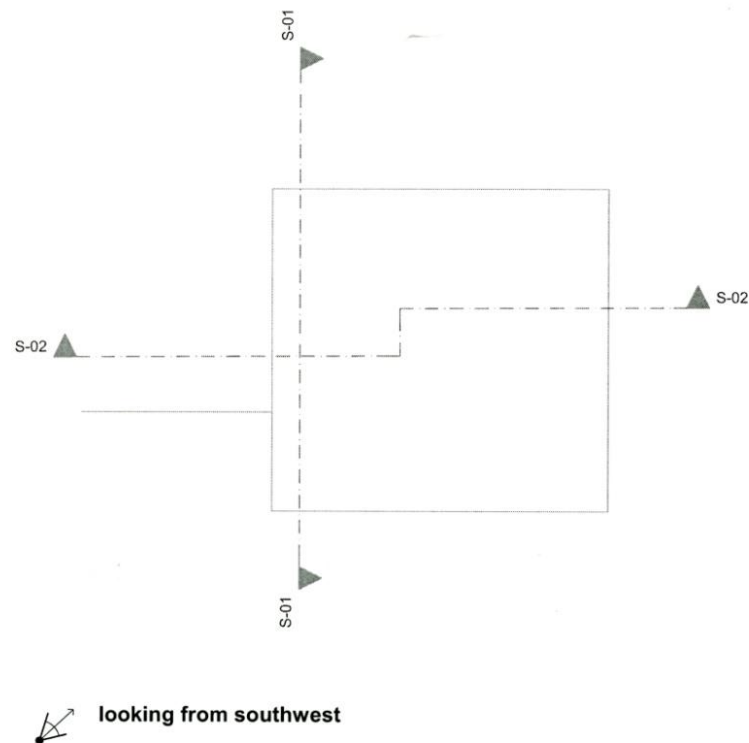


Figure 6 Location 1 at the southwest of B2

- Can you now draw what you see from there?
- Now, starting from your recent location, can you imagine yourself walking around the building in a clockwise direction (participant was shown the clockwise direction on an empty floor plan, as in Figure 7) and looking towards the building? Describe to me the appearance of the building from different directions as you walk around?

-
- The diagram shows a circular arena with a dashed boundary. Inside the arena is a solid square obstacle. A robot, represented by a small black dot with a line indicating its orientation, is positioned at the bottom left of the arena. A dashed line shows the robot's path, which moves clockwise around the square obstacle. The path is labeled with 'S-01' at the top and bottom, and 'S-02' at the left and right, indicating the sequence of waypoints or sensor readings along the path.

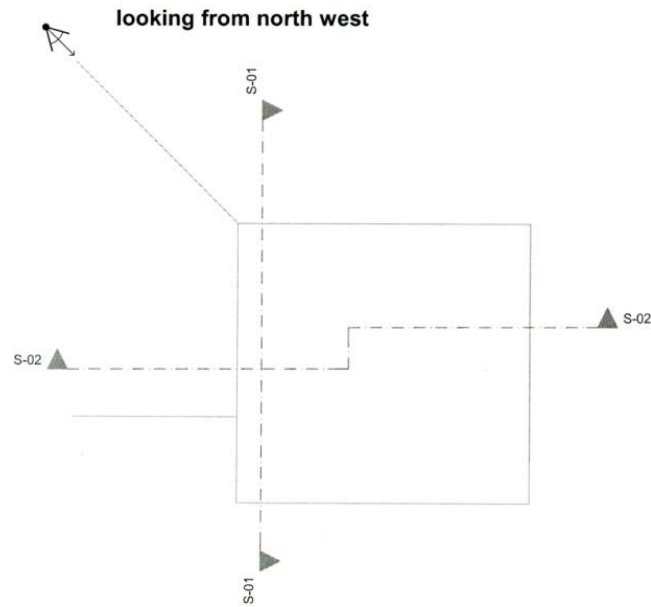


Figure 8 Location 2 at Northwest of B2

In this part of the study, there were a number of motivations behind the decision of asking the participants to verbally describe all their visualizations and to draw two of them in the tasks they imagined themselves at certain locations.

One of the motivations for requiring both verbal descriptions and drawings of the mental visualizations was to provide the participants two different means for communicating the 3D building information that they would capture during their mental visualization processes. One of the objectives in this study was to determine the 3D mental visualization performances of the participants i.e. the levels at which the participants would be able to mentally visualize the buildings in 3D based on their 2D drawings. This, as will be discussed in the analyses section, would be achieved by analyzing the 3D building information that the participants would be able to capture in two of the tasks where they would visualize the B1's interior space and B2's exterior form by imagining themselves standing⁴. In general, there were at least two major means

⁴ In the tasks where they would be asked to imagine themselves walking, the participants would basically be selecting which views of the building space or form to visualize. Accordingly, there would be

through which these participants' could express the 3D layout of the visualized building space or form; they could either draw or verbally describe them. Accordingly, the extent at which they could capture the 3D layout of the visualized building space/form in these tasks could be determined by looking at the 3D building information rendered in their drawings or in the context of their speech. If the participants were only asked to generate a drawing of their mental visualizations, some participants, particularly, mechanical engineering participants, might not be able to depict the 3D building information that they captured in their mental visualizations due to the possibility of their not being very skilled in drawing building environments. In such cases, the information rendered in the drawings would not be representative of all the information captured by the participants in their mental representations of the visualized building space or form. In addition, if the participants were asked to represent the visualized building space or form only by means of drawing, there was the possibility of the drawings supporting further inferences by providing immediate visual feedback to the participants. This could lead to drawings involving additional building information that might not be solely captured during the mental visualization process itself. On the contrary, if the participants were asked to first verbally describe their visualizations of the building space or form and then generate drawings of them, it would possible to (1) cross examine the information rendered in speech and the drawings, (2) find out any information that the participants could not depict in the drawings or that they added through reasoning on the basis of the drawings and (3) thereby derive at all the building information that the participants' could have captured in their mental representations of the visualized building space or form.

differences in the 3D building information that they would capture in their mental representations when carrying out these visualization tasks. Due to these differences it would not be feasible to examine the 3D building information captured by these participants on a common basis towards identifying their performances. This was why, in this study the performances were intended to be identified on the basis of the participants' visualizations of buildings in two of the tasks where they would create their visualizations by imagining themselves standing at the given locations.

In this study, another motivation behind the decision of asking participants to generate drawings of the mentally visualized building space and form was to examine these drawings towards identifying the nature of the mental representations that informed creation of these drawings. While the 3D building information rendered in the drawings would provide insights on the visuospatial aspects of the visualized building space/form captured in the participants' mental representation, the way the architecture participants' depicted these aspects would provide insights on how these various aspects of the building space/form could have been captured in the underlying mental representations. This understanding, as will be discussed in the analyses sections and the upcoming sections of the study, would be achieved by comparing the way architecture participants' depicted their mental visualizations with the way they depicted an actual building space by looking at it.

Two other motivations for requiring the verbal descriptions of the visualizations was the possibility that these participants, as observed in the participants descriptions in the pilot studies, would produce extensive amount of gestures during their verbal descriptions of their visualizations. These gestures, as will be reviewed in section 2.2.1, had the potential to provide substantive information that would not be available in speech and a unique window into the nature of the mental representations that underlie their creation. Their providing additional information would be critical for the performance analyses which would focus on the 3D building information captured by these participants in the mental representations they would create during their visualization processes. Their providing a window on the nature of the mental representations would have a significant contribution to this research as it is one of the objectives of this research study.

Section 5- Post-Study Interview

After the visualization tasks were completed, the participant was requested to provide a retrospective report of their mental visualization experiences while carrying out the 3D mental visualization tasks in this study through a semi-structured interview. The underlying motivation for this interview was the potential contribution of any supplemental information that the participants might provide to the interpretation of the collected data in an effort to elucidate the set of issues that this research intended to address. In this interview the participants were mainly asked about (1) how they thought they had carried out the 3D mental visualization tasks in this study, (2) what they thought the nature of these visualizations were in terms of their level of detail and vividness, (3) whether the interior and exterior visualization experiences differed, and (4) whether the participants faced any challenges. Some participants were further asked about some specific actions or aspects that had been observed in their visualization protocols. This interview was carried out based on a guiding framework established for the experimenter's use which lists the issues to be focused on with possible question forms and a further set of questions that might follow, depending on the content or the focus of a participant's response. The set of issues and phrasing of the possible questions defined for the post-study interview are listed in Appendix 1. After participants completed the 3D mental visualization part of the study in session one, they were scheduled for session two, in which they would take an SVA ability test and execute a perspective drawing task.

2.1.2 Assessment of Spatial Visualization Ability

In the second part of this study, participants were administered a paper-pencil test of spatial visualization ability, the Paper-Folding Test, taken from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French et al. 1976). Each problem of this test involves several figures drawn on the left side of a vertical line and five figures drawn on the right side of the vertical line, shown in the sample problem in Figure 9. The figures

on the left side represent a square piece of paper that was folded and then one or more holes punched in the folded paper. The last figure on the left represents the locations of the hole(s) that were punched throughout the thickness of the folded paper at that/those points. One of the figures on the right side of the vertical line represents where the holes will be located on the paper once the paper is completely unfolded. In this problem, participants are required to identify which figure on the right side of the bar correctly represents the location of the holes once the paper is unfolded. They do so by imagining folding and unfolding the square piece of paper. This test contains an instruction page and two parts with ten problems each. The participant has three minutes to complete each of the two parts of the test.

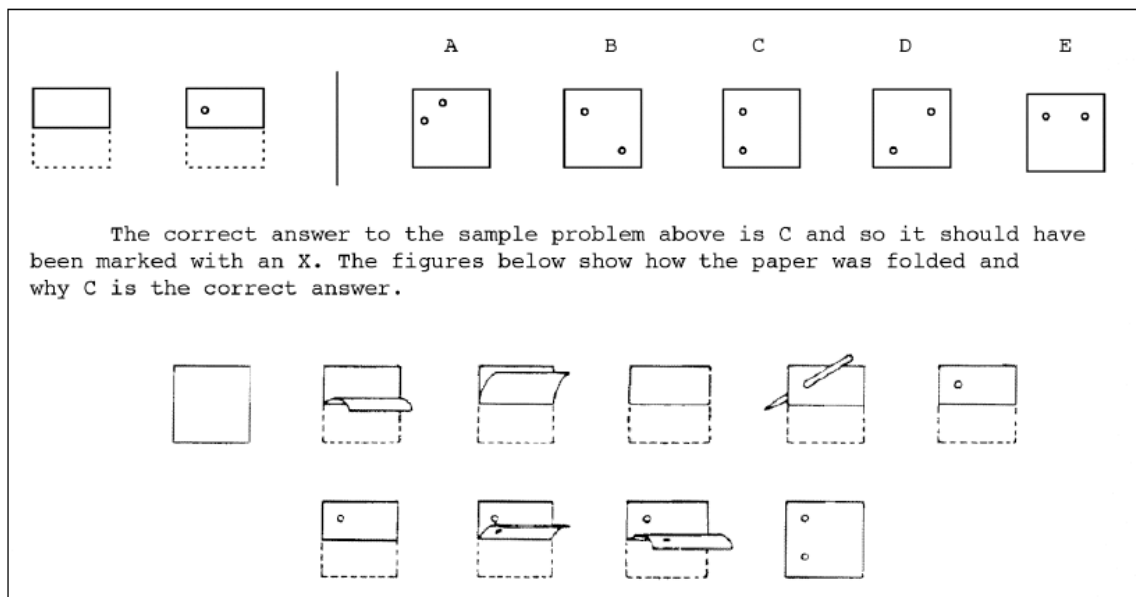


Figure 9 Sample paper-folding problem⁵

⁵ Ekstrom, R. B., J. W. French, et al. (1976). Manual for Kit of Factor-Referenced Cognitive Tests. New Jersey, Princeton: Educational Testing Service.

This test was administered to each participant of the study individually in the same room where the first session of the study was carried out. The participants were first provided the instruction page, which included the sample problem shown in Figure 9 and the instructions. When they were ready to proceed, they were given three minutes to complete the first part and then another three minutes to complete the second part.

2.1.3 Perspective Drawing Task

The third part of the study was a perspective drawing task. Previously, in the recall tasks, 3rd section of the 3D mental visualization part of the study, the participants were required to imagine themselves at a given location at a space inside a familiar building, their department/office buildings, and to describe and to generate a drawing of the appearance of that space from the given location. In this part of the study, to the same location inside that interior space of their department/office buildings and were required to generate a perspective drawing of that space while looking at it from that location. When the participants were taken to the location where the drawing would be generated, they were informed that:

- They were requested to generate a quick rough perspective drawing of the space that would capture the main forms of the elements in space; however, they did not have to render the textures of the building elements.
- The task was expected to take no more than 10 minutes of their time, but if they needed more time, they could take it.

After informed of the scope of the task, the participants were provided with materials such as sketching paper, a sketch pad, and pencils. Overall the time spent by the participants in generating their drawings varied between 7 minutes and 40 minutes with a total of 6 hours and 33 minutes.

The underlying motivation for acquiring individual perspective drawings of an actual building space was to be able to examine the drawings that participants generated

from their 3D mental visualizations of the building space/form in comparison to their drawings of an actual building space. Such a comparative examination would provide an opportunity to develop an understanding about whether what participants captured in their 3D mental visualizations from a certain location would be similar to what would be captured by the eye from that location in reality. Having the participants' drawings of an actual space would also provide the opportunity to explore whether there would be any characteristics that pertain to the drawings that participants generated from imagery including their drawings of their 3D mental visualizations and imaginations of a familiar space but not to the ones generated by looking at an actual building space.

2.2 Analysis of the Study Data

In this study, mainly two groups of analyses were carried out on the data collected at different sections. These include (1) the analyses conducted for investigating the participants' performances in the 3D mental visualization tasks and (2) the analyses conducted with the aim to develop an understanding about the features of the 3D mental visualizations and the nature of the mental representations that underlie them. Figure 10 charts the individual analyses involved in each group and the research questions that were aimed to be elucidated by each or a number of these analyses. It also outlines the set(s) of data which were collected at different sections of the study and examined in the context of each of these analyses. These data mainly include the protocols of the 3D mental visualization tasks that participants carried out in this study, the drawings that they generated in the various sections of this study and their SVA test scores. The information collected in the post-study interviews was not included in any of these analyses since this information was mainly treated as a supplementary data that might provide insights in the interpretation of the results of the analyses'. As can be seen in Figure 10, one further analysis conducted in this study was the comparative analysis of the drawings that architects generated in this study to investigate any potential difference between

imaginations versus perceptions of the appearance of building space/form. This section first gives a brief overview of literature on gestures in cognitive science with regard to two of their underlined roles, providing substantive information that is not available in speech and providing a window to the nature of the mental representations, as they motivated and provided a basis in the examination of the gestures that participants produced during their verbal descriptions of their visualizations in the context of this study. It then discusses each of these conducted analyses in detail including their structure and the examined set(s) of data.

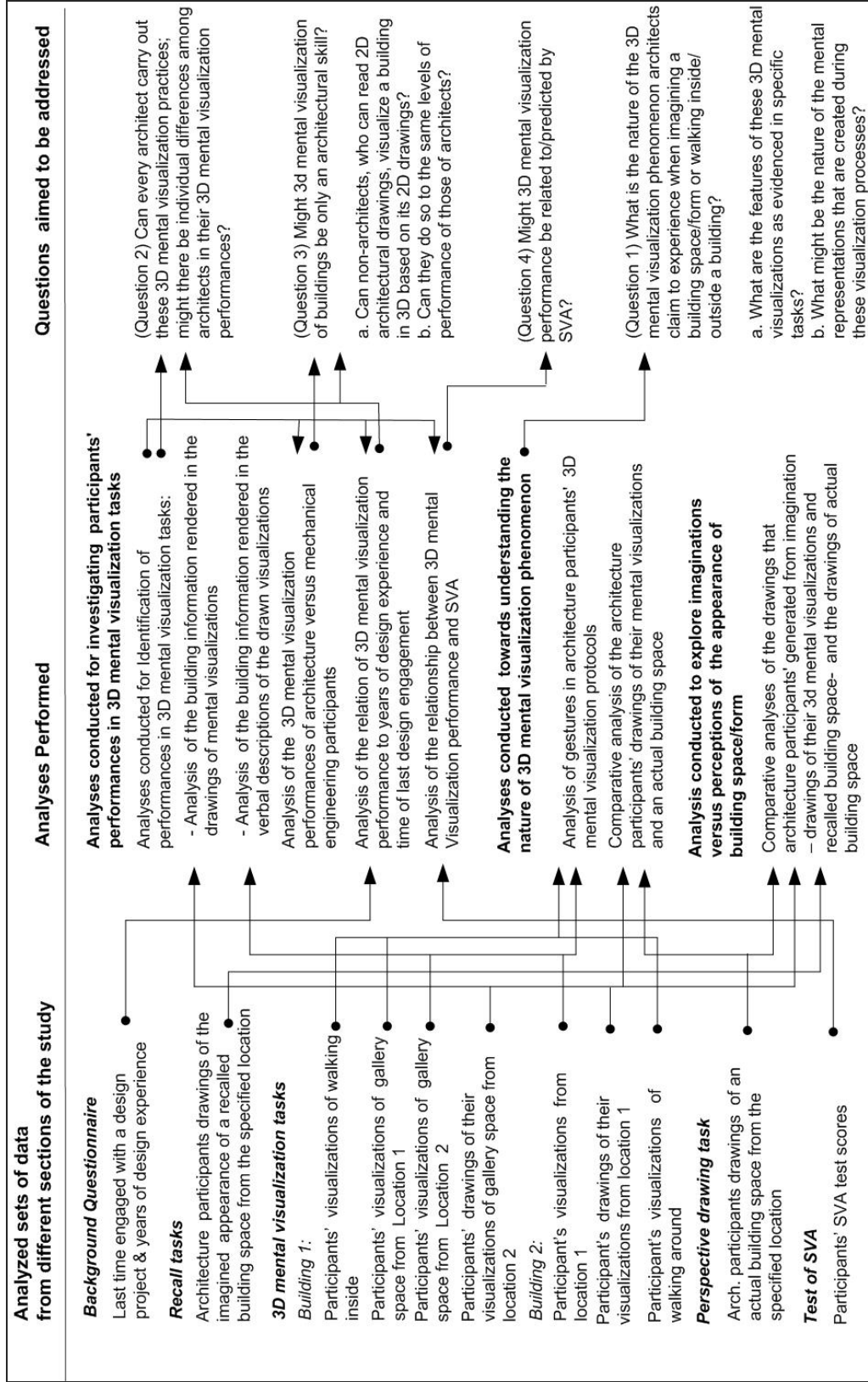


Figure 10 Framework of Analyses

2.2.1 Literature on Gestures

There is substantial evidence that the spontaneous gestures that people produce along speech do not always convey the same information conveyed with the accompanied unit of speech and sometimes they convey information that is not conveyed in speech (Church and Goldin-Meadow 1986; Schwartz and Black 1996a). For instance, a child, in a study, when asked to describe her judgment on whether the amount of water changed after it was poured from a skinny tall container to a wide short container, after saying that it had changed, expressed that “cause this one’s lower than this one” in speech. While expressing this, she provided substantive information about the widths of two containers first the lower one by holding her c shaped hands as if holding a wide container and then the higher skinny one by only holding one of her hands in c shape as if holding a skinny glass with one hand. There is also extensive evidence that people tend to gesture when carrying out spatial tasks or talking about spatial information (e.g. Alibali, Heath et al. 2001; Wesp, Hess et al. 2001; Kita and Özyürek 2003; Morsella and Krauss 2004) such as when giving route directions (Allen 2003) or describing motion in space (Kita and Özyürek 2003). The gestures that people produce when talking about spatial information are mostly iconic⁶ or deictic⁷ in nature that represents the shapes of objects or people, trajectories of movement or indicate objects, people, etc., demonstratively. Gestures convey information through imagery which can simultaneously present information that can only be conveyed sequentially in speech. This makes them unrestricted, unlike speech, and able to vary on dimensions on space, time, form and etc. (Goldin-Meadow 2003) and very suitable means for conveying spatial and temporal information.

⁶ Iconic represent “body movements, movements of objects, or people in space, shapes of objects or people... concretely and transparently” such as one’s drawing a circle when talking about mirror that has a circular form (Goldin-Meadow 2003)

⁷ the deictic gestures which are “used to indicate objects, people and locations in real world”, yet “ they do not always indicate visible objects or people” such as one’s pointing to his left while saying ‘you will see dean’s office there’ to indicate that the dean’s office will be on the listeners’ left (Goldin-Meadow, 2003).

Besides their communicating substantial information that is not available in speech, there has been growing amount of research on the various roles that gestures play. Among their findings, one of the most intriguing ones for this study was that gestures can provide a unique window to the speakers' mental representations (Goldin-Meadow 2003) such as that they can provide insights on the speaker's problem solving strategies for both children and adults, they can reveal people's mental representation of a presented problem or knowledge on about a topic (Crowder and Newman 1993) and they can give access to the perspective that people take on the spatial information (McNeil 1992). For instance, in a study (Perry, Church et al. 1988) children from fourth and fifth grades were presented with simple equations, such as $4 + 5 + 6 = _ + 6$, on the board, were requested to solve the problem in front of the board by presenting the answer and then explaining how they reached at that answer. One of the wrong solution strategies that were commonly applied in this problem was the add-all strategy where the students add all the numbers at both sides of the equation and find the solution as 15. One of the right solution strategies was the grouping strategy in which they were aware that the numbers at different sides of the equations are two different groups to compare. In the examination of the protocols, where students did not find the correct answer, researchers found that some of these students presented two different strategies in their speech and in the gestures they produced. The strategy they defined in speech was the add-all strategy on the basis of which they reached at an incorrect answer. On the contrary the strategy they expressed through the gestures they produced during speech was the grouping strategy. The researchers had considered the correct solution strategy represented in the gestures as an outward manifestation of students tacit awareness of the correct solution strategy. The students' did not have a single and stable mental representation of the solution strategy; they were in an unstable state with regard to the solution strategy to apply in this problem, rather than a stable representation of a wrong solution strategy. The researchers considered that these students' unstableness of the mental representation

of the solution strategy could mean that they could be more open to instruction than those who have a stable representation of the incorrect strategy as the strategy to apply in these problems. In following studies, after giving training to the students about equations, they found that the mismatching children who indicated instability had more improvement than matchers. In this research the gesture's representing a different solution strategy than that was represented in speech, provided a unique insight to these researchers about the children's mental representations of the solution strategies and their not having a stable mental representation but rather different instable representations.

In this research, in the first group of analyses that focused on identifying the 3D mental visualization performance of the participants', the gestures produced in the context of the verbal descriptions are looked at from the perspective of their providing additional information that is not available in speech. In the second group of analyses that were aimed at understanding the nature of the 3D mental visualization phenomenon, these gestures were examined as outward manifestations of and window to the imagistic representations of the buildings that architects constructed during their visualization processes. The rest of this chapter outlines these two groups of analyses.

2.2.2 Analyses Conducted for Investigating Participants' Performances in 3D

Mental Visualization Tasks

Analysis of the participants' drawings and verbal descriptions for identifying their 3D mental visualization performances

In the context of this study, the participants' 3D mental visualization performances in the visualization tasks were determined by close examination of the 3D building information rendered by in their drawings of their visualizations of B1 gallery space from location 2 and B2 from location 1 and in their verbal descriptions of these drawn visualizations where they conveyed building information through speech as well

as the gestures they produced along speech. In this analysis, as I outlined previously, the primary consideration for examining both the drawings and verbal descriptions of the participants' mental visualizations in these tasks was that some participants could have conveyed some building information only in their verbal descriptions but not in their drawings. Thus, doing both analyses would ensure that all the 3D building information rendered in the participants' mental visualizations of that building space/form would be taken into account in determining their 3D mental visualization performances. This is why; the analysis of their performances was carried out in two steps. The first step involved the examination of the drawings by looking at the building components that the participants rendered in them, the accuracy of their spatial locations and relations in the 3D building space or form. In the second step, the information rendered in the participants' verbal descriptions of the drawn view were closely examined from the same perspectives in order to identify whether there was any building information that was covered in the descriptions but not depicted in the drawings. This analysis is detailed in Chapter 3.

Statistical Analyses

After each of the participant's performance scores on the interior and exterior visualization tasks were determined based on the above analyses, a number of statistical analyses were conducted. The research questions to be addressed with these analyses and the issues that were investigated can be summarized as follows:

- (2) Can every architect carry out these 3D mental visualization practices; might there be individual differences among architects in their performance in these practices?
 - Examination of the architecture participant's 3D mental visualization task performances
- (3) Might 3D mental visualization of buildings be only an architectural skill?

- a. Can non-architects, who can read 2D architectural drawings, visualize a building in 3D based on its 2D drawings?
- Examination of the mechanical engineering participant's 3D mental visualization task performances
- b. Can they do so to the same levels of performance of those of architects?
- Analysis of the 3D mental visualization performances differences between architecture and mechanical engineering participants
- (4) Can performance in 3D mental visualization tasks be related to/predicted by SVA?
- Analysis of the relationship between 3D mental visualization performance and SVA as measured by Paper-Folding test.

In the context of this study the participants' spatial visualization ability levels were determined based on the scores they obtained from the paper folding test of SVA taken from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French et al. 1976). These scores were identified manually by (1) identifying the problems that were answered right and wrong based on the answer sheet provided in the Kit and (2) calculating the test scores based on the formula provided in the Kit for calculating the scores with a correction factor for guessing. This formula was $R - W / (n - 1)$, where R is the number of correct responses, W is the number of wrong responses, and n is the number of response options for each problem.

In addition to the above analyses, statistical analyses were conducted to look at the relationship between performance in 3D mental visualization tasks and the years of design experience and the 3D mental visualization performance and the time passed since the last engagement with design. The motivations for these analyses was to explore (1) whether these two factors can be sources of the possible individual differences among architecture participants' 3D mental visualization performances and (2) whether 3D

mental visualization skills, If they were architectural skills, could be becoming heightened with professional work experience. These analyses are discussed in Chapter 4.

2.2.3 Analysis Performed Towards Understanding the Nature of the 3D Mental Visualization Phenomenon

A primary objective in this study was to develop an understanding about the features of the 3D mental visualizations and the nature of the underlying representations that architecture participants construct during such visualizations of a building based on the 2D drawings. For this purpose, two major analyses were conducted in this study on each of the two different forms of external representations that the architecture participants generated to depict their 3D mental visualizations. One of these external representations was the drawings that the participants generated from their 3D mental visualizations of B1's interior space and B2's exterior form from the locations specified by the experimenter. The other form of external representation was the depictive⁸ gestures (as shortly be referred as gestures in the rest of this discussion) that the participants' produced within the context of their verbal descriptions of their 3D mental visualizations. The rest of this section discusses how each of these analyses was conducted in detail. The discussions of the results of the analyses are discussed in Chapters 5 and 6.

Analysis of Gestures in Architecture Participants' 3D Mental Visualization Protocols

During their verbal descriptions in their visualization protocols of 3D mental visualization tasks, most of the architecture participants produced an extensive amount of gestures, such as pointing their hands to relative directions in space to indicate their locations, or depicting the shape of an element. There were also instances, where the participants moved their hands in the air drawing the trajectory of climbing the stairs or

⁸ Here the term depictive gesture is used as a high level term to refer to both iconic and deictic gestures.

where they draw the plan layout of the building elements in 2D by moving their index finger on the table surface. When examined as individual units, these gestures were seen conveying substantial information about the visuospatial aspects of the entity that was being described in the accompanying units of speech. When the sequence of gestures are examined, gestures accompanying the descriptions seemed to render a common representation of that visualized building space/form in the gesture space, as though these were outward manifestations of a common imagistic representation of the building. For instance, some participants were rendering the spatial locations, shapes and the dimensions of the components in their gesture spaces as if at the time they were simultaneously imagining being within that building environment and visualizing that space/form in nearly the actual size. Some participants, while depicting the 3D arrangement of the various building components -their spatial locations, relations, shapes and sizes- were simultaneously rendering an invisible 3D small scale of the visualized building or building space or form in their gesture spaces as if they were at the time imagining a 3D small scale model of that portion of the building. In some occurrences, they were rendering a portion of the 2D floor layout by pointing to locations or drawing invisible lines on the table surface or an invisible horizontal plane above the table as if they were imagining that small scale 2D layout of that portion of the building at the time.

Further, in some visualization protocols, the sequences of gestures produced by the participant at different time intervals of the speech were rendering portions of the visualized building space/form or the building in different forms as if they were switching between different forms of representations of the space. For instance, while the gestures produced by the participant up to a point in the description were rendering a 2D plan layout of the building, the sequence of gestures produced from that point on to another point in the description were forming a small scale 3D model of the portion of the building that was being described.

Having observed these occurrences during the collection and reviewing of the protocols, a major objective of the analysis of nature of the architects 3D mental representations became determining the patterns of gestures which render a common representation of the visualized building space/form or a portion of it in order to infer the characteristics of the imagistic representations that underlie them.

In addition to the hand movements, there were also occurrences of body movements, eye movements and eye fixations during participants' explanations of their mental visualizations which were orchestrated with the gestures and point to the same common imagistic representation of the described building space/form. For instance, some participants were turning their heads to different sides while they were pointing to the locations of the different components in space and depicting their shapes as if they were located inside that space at that moment and turning their heads to look towards these different components. Examining such utterances of non-verbal expressions to the extent that they could be captured in the video recordings would be beyond the scope of this study. Yet it was not possible to overlook them either. Therefore it should be noted that such other non-verbal utterances by the very nature of the conducted analysis contributed to interpretations made in this context.

Structure of the Analysis:

For preliminary analysis a sample of four video records of the architecture participants' verbal descriptions of their visualizations were initially segmented and coded at two levels of granularity: a macro and a micro level. At the macro level, the video record of each participant's verbally reported views and walkthroughs were watched with a careful examination of the gestures that co-occurred with speech. Here the intent was to see whether the sequences of gestures produced by the participant throughout the speech or at certain episodes of the speech render a common representation of the visualized building space/form or portion of it. When such episodes

were identified, they were marked on the written transcripts of the verbal statements (by indicating from what point to what point of the speech they were observed) and notes were taken about how these participants appear to be visualizing the described space/form or portion of the building during this episode.

After analyzing these participant's videos at the macro level, the videos of each participant were then encoded at a micro level, i.e., at the level of individual gestures. Here, each gesture that accompanied speech were first marked on the written transcripts of the units of speech they accompanied (by underlining them). Then the verbal statements were segmented into phrases during which a gesture is produced. Here the focus was on segmenting the speech based on utterances of the gestures rather than looking for smallest coherent segments. After all the gestures are marked in relation to the verbal expressions, the videos of the participants were examined in a step by step fashion to produce a written transcript of each gesture, the information it conveys regarding the element that is being described, and in what form the participant at that moment seems to be imagining that component in space. An example portion of a macro and micro level coding of participant's protocol can be seen in Appendix 2.

After videos from four participant's descriptions of the buildings from different locations were analyzed at both levels of detail, it was found that both analyses support the same inferences. Thus, the micro level analysis was redundant for the purposes of this analysis. Further, given the time necessary to carry out the micro level coding, it would be infeasible to do for this dissertation. Accordingly, the analysis of the remaining visualization protocols was carried out at only the macro level.

Examination of Gestures by an External Reviewer

In order to seek reliability the inferences that were made in this analysis regarding the interpretations of the gestures and the representational form in which the participant appeared to be visualizing the described building portion/ space/form, an external

reviewer was requested to review segments from the video records of participants' verbal descriptions. In this review, he was requested to closely observe the participants' gestures and look at whether the participant appears to be describing that space/form/portion of the building by (1) imagining to be within that building environment, (2) imagining that space/portion/form of the building much like in the form of a small scale model of the building, (3) imagining a 2D small scale drawing of that portion of the layout, and (4) none of them (as in the format presented in Appendix 2). He was requested to write about any other observations he made and whether he observed any gesture that seemed to be different from the others in the way it depicts the building component/space/layout, and if so, whether he could define this observed difference.

The segments provided to the reviewer were the episodes from the videos where, in the context of the macro analysis, the participant had been observed to the visualizing the described building space/form/portion in one of the three observed forms. In order to provide a feasible number of segments to the reviewer, the reviewer was given two sample episodes of imagining the 2D layout, three sample episodes of imagining from within and 3 sample episodes of imagining in the form of small scale model. These sample segments of the videos were provided to the reviewer in a mixed order as video files under a folder from which he can randomly select which one to watch.

For the review of the given video segments, the reviewer was first introduced to the 3D building models by showing him the 3D computer model of the each building generated from various perspectives along with the various drawings of the different views of the building. Then he was given the review list and was requested to watch the given videos and respond to the queries in the list. Just after he completed the review, the reviewer was asked to explain any comments made on the review sheet to ensure that the meaning he wanted to convey was interpreted correctly and to understand whether there are commonalities and differences between the two rater's interpretations. Overall, the percentage of agreement between the two raters was found to be %100 on the three forms

of visualization observed. There were seven comments made by the external reviewer where he pointed out gestures that he found to be different than the others in those participants' protocols. After being asked about his statements, it was understood that both reviewers observed the same aspect about the depiction of the component that it was being depicted outside its spatial context. There were two other gestures which were interpreted in the same way but were not captured by the reviewer. Upon request he was requested to watch segments from the participant's video in which they occurred and asked if he could recognize existence of a different gesture. In this second review the external reviewer captured and indicated the two different gestures. Thus a %100 agreement was reached at the identification of the different gestures in terms of their focusing on a component and depicting its attribute independent of its spatial context and the scale of the space.

Comparative Analysis of the Architecture Participants' Drawings of the Mentally Visualized Building Space/Form and ABS

The aim of this comparative analysis was to develop an understanding about whether what architecture participants captured in their 3D mental visualizations of a building space/form from a certain location could be similar to how they would be captured from that certain location in reality. For this purpose, these participants' drawings of the mentally visualized building space/form from the given viewpoint location were examined in comparison with their drawings of an actual building space from the given location based on three major characteristics. These characteristics include (1) the location and direction of the viewpoint taken, (2) the approximate relative proportions of the components and the containing space/form and (3) visibility of the depicted components from the given locations.

As discussed in the procedure section, in the 3D mental visualization tasks the participants were required to visualize the building space/form from a particular location

and direction which was specified on the spot by showing a symbolic footprint of that floor level/the building on site. After their verbal descriptions of their visualizations, they were requested to draw their visualizations of the building space/form from the given locations. While being requested to draw their mental visualizations, no specific drawing technique was mentioned. They were simply asked to draw what they see from there (in reference to the given location in the visualization task). The decision was not to specify drawing a perspective projection from the given location, since they might have imagined the building space/form in a different form and their drawings could shed light to this. Yet, if they asked specifically to how to draw the visualized space/form they would be told to draw in a perspective view from the given location. All of the architecture participants, after either mentioning or asking about it ⁹and being informed that they should do so, generated their drawings with the intention to draw a perspective view of the visualized space/form from the given location. In the case of the actual building drawing task, all the participants were taken to the same location inside the space and were requested to look towards in the same direction and generate a perspective drawing of that building space. Thus, all the drawings that were examined in this analysis were the drawings generated with the intention to depict the space in perspective from the specified locations.

The first set of characteristics that were looked at involved the location and direction of the viewpoint from which the building space/form depicted by the participants. Here the objective was not whether the space/form was correctly depicted as would be seen from a specific viewpoint such that whether the drawing is a legitimate perspective drawing in terms of the distortions in the dimensions along the sightline and objects appearing smaller as the distance between the objects and viewpoint location increases. Rather, the objective was to (1) determine whether the participant were able at

⁹ Some participants after starting to draw the building space/composition from a different perspective asked if they should have been drawing an eye-level perspective; in these cases the participants were told they should have and requested to do so if possible.

all to depict the aspects of the actual building space and the mentally visualized interior space of B1 and exterior appearance of B2 from the specified viewpoint locations and in the given directions and (2) in case not, to identify the location of the viewpoint and the direction of view adapted by them in the drawings¹⁰.

In this analysis, the locations and directions of the viewpoints as well as to which extent the architecture participants could capture the relative proportions and visibility of the depicted components in their drawings of the actual building space was examined on the basis of a picture of this space which was taken from the location the participants generated their drawings. In the architects' drawings of their mental visualizations of B1's interior space and B2's exterior space from the given locations, these characteristics were examined by generating views of the B1's interior space and B2's exterior form from their computer models which would be closest to the views depicted in each participant's drawings. For the generation of these closest views of B1, an image the participant's drawing of B1's interior space was laid next to the rendered 3D computer model of the building in which the building space was looked at from the given location. Then taking the participant's drawing as a basis, the location (and also the cone of view in some cases) and direction of sightline of the camera were altered to capture the closest view to the one depicted in the participants' drawing. When searching for the closest view, the angle and the direction from which the components were depicted in the participant's drawing were taken as the basis, since in this way it was possible to determine from which viewpoint location (both on layout and the Z axis) in 3D space such a view of the component can be captured. Through various iterations, the closest view of the space to that of the one depicted by the participant was captured. In this process it was found that some of the participants adapted multiple viewpoints in their depictions different portions of the building space. In cases where a closest view was

¹⁰ Identifying the location of their adapted viewpoints were of critical importance as the further two characteristics would rely on the way the building space/form appears from the adapted viewpoints.

captured from the 3D model from a single viewpoint, the location of the viewpoint and direction of view in the closest view were identified and recorded as the approximate location of the participant's viewpoint. Then the identified location and direction were compared with the specified location and direction from which the participant was requested to draw the building space. The difference between the two was then calculated to see if the difference between the viewpoint locations was more than 1 meter in any of the 3 axes and if the direction in which the building space is looked at is altered more than 20 degrees. In case the difference was less than these values, the location and direction of the viewpoint adapted by the participant in their drawing of the visualized building space were considered as approximately accurate. If not, it was considered as not depicted from the given location and/or in direction. The same procedure was followed to generate the closest views to the ones depicted by all the 13 architecture participant's drawings of B2's exterior form.

After setting up the closest views and identifying the adapted viewpoint(s) by the participants in their drawings of B1's interior and B2's exterior space, the second characteristic that was looked at in these drawings was the approximate relative proportions of the components and the containing space/form. Here the relative proportions represent two basic characteristics that would be seen in a perspective drawing of a scene which captures the appearance of the scene as would be seen by the eye. These were (1) as the distance between the point of view and the objects in a scene increases, the objects appear smaller and (2) the objects' internal dimensions become disproportionate, such that the dimensions parallel to the line of sight appear relatively smaller than the dimensions that are at angles to the line of sight (which is mostly referred as foreshortening in perspective drawing). Here the objective was to determine whether the participants had been able to depict the approximate relative proportions of the components and the containing space/form in their drawings of their mental visualizations from the given or adapted viewpoints to the extent that they were able to

do so in their drawings of the actual space. This analysis was conducted by visual examination of the drawings of the actual building space on the basis of its picture and examinations of the visualized building space/form on the basis of the generated closest views.

The third characteristic that was looked at in these drawings was the visibility of the depicted components from the given or adapted viewpoint locations. Normally when looking at an actual building space/form, one can only see the components that fall into one's visual field and the components to be seen mainly depend on the location and the direction of one's orientation in a building environment. The objective of this analysis was to find out whether the components depicted in the participants' drawings of mentally visualized building space and form were the ones that would normally be visible from the given/adapted viewpoint locations and whether there are any components that would not normally be visible from that adapted viewpoint location. This analysis was also carried out by comparing the participants' drawings of the actual space with its picture and participants' drawings of the mentally visualized space/form with the closest views generated from the computer model.

2.2.3 Comparative Analysis of the Architecture Participants' Drawings of the Mentally Visualized Building Space/Form, ABS and RBS

Finally, a brief comparison was made among (1) the drawings that architects generated from their 3D mental visualizations of the appearance of the study buildings spaces, (2) their drawings of a familiar building space that they imagined by recalling it from memory and (3) their drawings of a real building space that they generated by looking at that space. Since both (1) and (2) were the drawings that were generated from imagination, it was thought that a comparison of these drawings and the drawings (3) that they generated by looking at a real building space might provide some insights about whether there could be some characteristics that pertain to drawings created from

imagination but not the drawings generated from perception of building environments. This analysis was mainly carried out by visually cross examining these different drawings to see whether there would be any features that would be commonly found in the drawings that participants generated from a solely imagined space but did not exist in their drawings of an actual space or vice versa.

CHAPTER 3

ANALYSES OF 3D MENTAL VISUALIZATION PERFORMANCE

This chapter outlines and presents the results of the analysis that was conducted with the aim to identify the participants' 3D mental visualization performances. In this analysis the participants' 3D mental visualization performances in the visualization tasks was determined by examining the 3D building information that they rendered in two of the visualization tasks where they both verbally described and generated a drawing of the visualizations. These were the tasks where they visualized the interior gallery space of B1 from location 1, and the exterior form of B2 from location 1. This analysis was carried out on in two steps which involved the examination of the information rendered by these participants in their drawings and in the context of their verbal descriptions respectively. The following two sections of this chapter describe each of these two steps. The last section reports the 3D performance scores of the participants' identified based on this analysis.

3.1 Analysis of the Drawings

In this analysis, the participants' drawings of their visualizations of the B1's gallery space and B2's exterior form from the given locations were examined based on a component based evaluation scheme. This scheme mainly involved (1) the list of building components that would normally be seen in the visualized the building space/form when looked from the given location and (2) three categories based on which building component would be evaluated and graded. These three categories follow:

- Existence: whether the listed building component was present in the participant's drawing regardless of the accuracy of its 3D form properties

- Form properties: whether the 3D geometry of the present building components (i.e., their shape and size) and in some cases, material properties, such as being a solid concrete parapet wall versus a railing) were captured accurately
- Spatial location/relation: whether the component was located accurately in the 3D building space/form

Table 2 and Table 3, presented on the following pages, exemplify the main structure of the evaluation schemes developed for the performance assessment of two participants', A11 and A4, drawings of their visualizations of the B2 from the exterior and B1's gallery space from the interior respectively. The remainder of this section first describes how these evaluation schemes were developed and then how the drawings were assessed and scored based on the evaluation schemes.

3.1.1 Development of the Evaluation Scheme

The evaluation schemes for each view were established in two major steps which involved:

- identification of the building components that should be included and searched for in the assessment of each participant's perspective views (the first two columns of the evaluation scheme: 'components' and 'inclusion')
- identification of the categories of assessment for each of the building components; which of the three sub-categories should be included in the evaluation of the component; what their weights should be in scoring

Identification of the Building Components to be Included in the Evaluation

Most of the participants in their drawings of their visualizations of B1's interior space and B2's exterior form did not exactly depicted the building space and/or form from the given viewpoint locations and adapted different viewpoints (as exemplified in Figure 11). Furthermore some participants' in their drawings of the interior space of B1

adapted wider fields of view (up to around 160-170 degrees) than those of the others. This resulted in variances in the components of the building space and form rendered in different participants' drawings. As the aim of this analysis was to assess whether the participants could visualize the 3D building composition based on its 2D drawings, it would not have been reasonable or practical to evaluate every participant's drawing based on the same set of building components that would be depicted in the drawing of that building space/form from the given viewpoint location and within a certain visual span. To account for such slight individual differences in the viewpoints and/or visual spans and in turn the set of building components depicted, the evaluation schemes for the assessment of the participants' the drawings were developed in two phases.

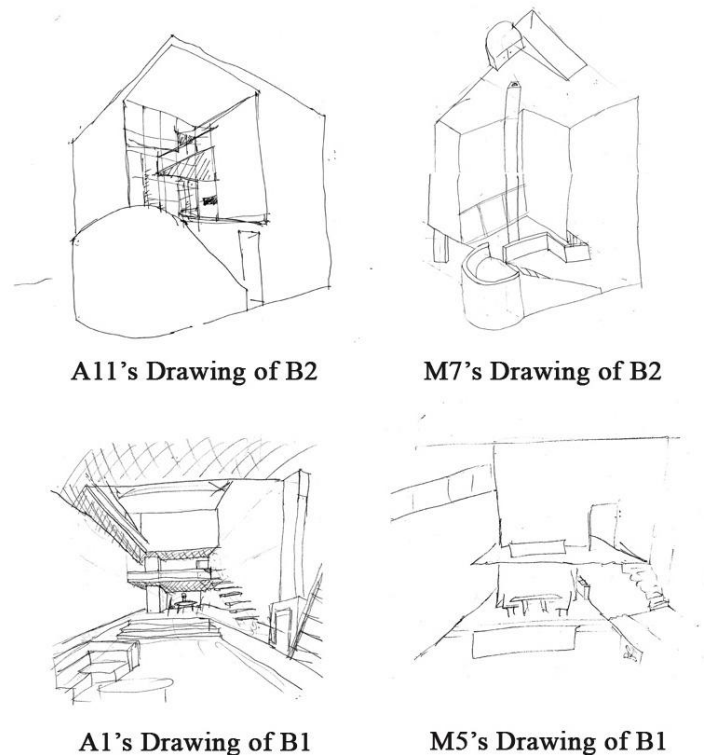
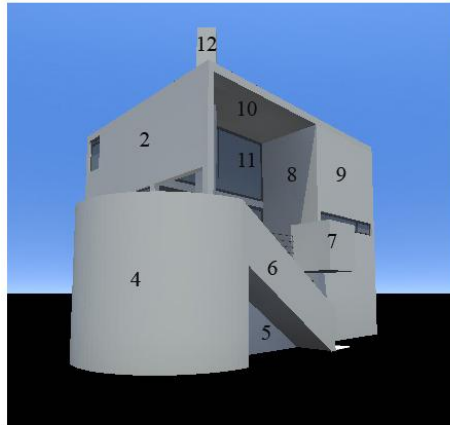


Figure 11 Example of different viewpoints adapted by the participants

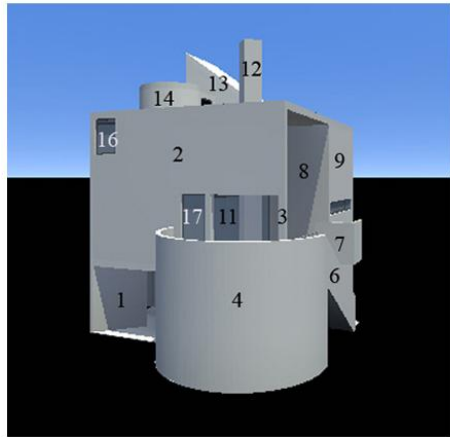
For the assessment of the drawings of B2's exterior view, in the first phase, a number of perspective views were generated from the computer model of the building by adapting viewpoint locations that were slightly different than the given viewpoint location on the southwest. Then, all the components that could be seen in these generated views, as shown in Figure 12, were aggregated and listed to establish a general evaluation scheme which involves the largest possible set of components (column 2, Table 2) that could be seen at the southwest side of the B2. In the second phase, each participant's drawing was examined to identify which of the listed building components in the largest possible set would rationally be seen within the view of the building depicted by the participant. For instance, in the examination of participant A11's drawing of B2 (Figure 14) it was seen that the components the angular wall (component 1 in Figure 12), the skylight triangular mass (component 13 in Figure 12), and the cylindrical stair block (component 14 in Figure 12) remained rationally hidden due to the viewpoint taken. Accordingly, these three components were marked with the letter N (no for inclusion) in the inclusion column of the evaluation scheme (column 3, Table 2) in order not to be included in the analysis of that participant's drawing. Likewise, it was seen that the components, which were indicated with Y (yes for inclusion) in the inclusion column of the evaluation scheme (column 3, Table 2) would be the ones to be included in depicted the view of the building in the participant's drawing. Carrying out the same procedure for each of the participants' drawings of the B2's exterior form, a participant specific evaluation scheme was developed for assessment of each participant's drawings of B2.

In participants' drawings of the interior space of B1, the variations among the drawn views and in turn the depicted components were mostly a result of the differences in the adapted field of views. For the assessment of these drawings, first, the smallest set of components that would be seen from the given location were identified by generating a 60 degree view of the space from its computer model as in Figure 13. These components then were listed to develop a general evaluation scheme which involves the least common

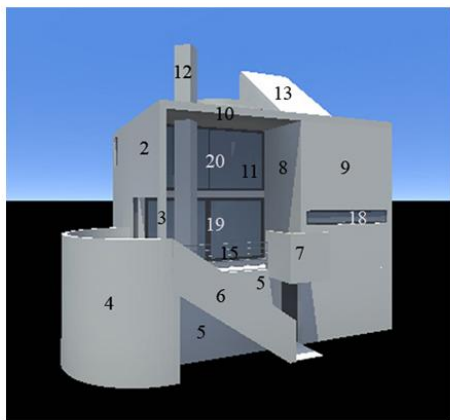
set of components (as in Table 3) that could be seen if one were to look at the depicted portion of the space from the same side with the given viewpoint location. Then by increasing the cone of vision up to 140 degrees as in Figure 13, the largest set of building components that could be seen from that location was identified, and the building components that were not included in the smallest set were added to the list of components as ‘other components’ as in Table 3. In the second phase, each of the participant’s drawings were examined to identify which of the building components in the smallest set would rationally be rendered in their drawings of the space; these components were marked with Y on the evaluation scheme for inclusion in assessment. Likewise any components from the smallest set that would reasonably not be rendered in their drawings were marked with N for not to be included in the assessment. Then the participant’s drawing was examined to see which other components were depicted in the drawing as a result of adapting a wider field of view and these components were marked with Y for inclusion in the assessment; from the set of other components the ones that are not depicted in the participant’s drawing were marked with N not to be included in the assessment. This way it was ensured that the participant would not lose any points due to adapting a wider field of view and depicting more building components than others but rather gain points for them. For instance, as can be seen in Figure 15 and column 3 of Table 3, participant A4 adapted a wider field of view in his drawing and depicted various components from the set of ‘other components’ and they were included in the assessment of his drawing. Carrying out the same procedure for each of the participants’ drawings of the interior space of B1, a participant specific evaluation scheme was developed for assessment of each participant’s drawings of this space.



View of Building 2 from given location



Alternative view 1

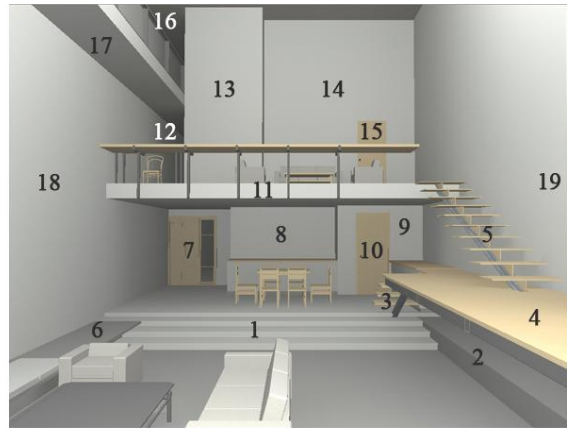


Alternative view 2

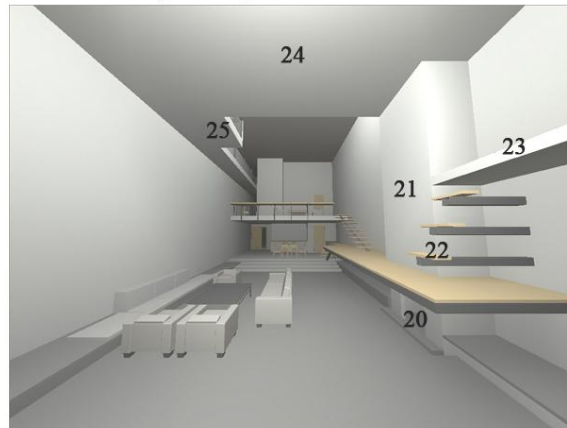
Building Components (largest set):

- 1- Angular wall
- 2- Living room west wall
- 3- Terrace column
- 4- Curved study room wall
- 5- Study room south wall
- 6- Stair block
- 7- Balcony block
- 8- Service core west wall
- 9- Service Core south wall
- 10- Canopy
- 11- Living room south wall
- 12- Chimney
- 13- Skylight triangular mass
- 14- Cylindrical stair block
- 15- Terrace railing
- 16- Living room window west 2nd floor
- 17- Living room window west 1st floor
- 18- Kitchen window
- 19- Living room south wall window 1st floor
- 20- Living room south wall window 2nd floor.

Figure 12 Identification of the visible components of B2 from different viewpoints for establishing the evaluation scheme



View of Building 1 from given location- View cone = 60°



Wider view - View Cone = 120

Building Components (smallest set):

- 1- Liv. room main stair
- 2- Liv. room surrounding platform right side
- 3- Stair first leg from dining area
- 4- Raised platform-stair landing
- 5- Stair second leg to balcony
- 6- Liv. room surrounding platform left side
- 7- Door/Opening to corridor 1st floor
- 8- Dining area back wall
- 9- Kitchen area protruding wall
- 10- Door/Opening to kitchen area
- 11- Balcony Slab with railing
- 12- Opening to 2nd floor corridor
- 13- Protruding wall sauna, mechanical room 2nd and 3rd floors
- 14- Wall bathroom, mechanical room 2nd and 3rd floors
- 15- Door/Opening to dressing room
- 16- Opening to 3rd floor corridor
- 17- Bridge
- 18- North wall
- 19- South wall

Other Building Components:

- 20- Fireplace
- 21- Walls surrounding chimney
- 22- Ladder
- 23- Raised platform to green house
- 24- Guestroom slab
- 25- Bridge -Guestroom corner slab

Figure 13 Identification of the visible components of B1 based on different visual cones for establishing the evaluation scheme

Identification of the Categories to be Incorporated in the Evaluation of a Building

Component

The categories according to which a building component would be evaluated were mainly determined based on the information about the component that was available in the drawings. Except for the building components, whose height and thereby shape information was not available in the drawings, all the building components listed in the evaluation scheme, as can be seen in Table 2 and Table 3, were determined to be assessed on all three categories i.e. their existence in the drawing, the accuracy of the characteristics of their form, including shape and dimensions, and the accuracy of their spatial locations in the building composition. The building components, whose shape information was not available in the drawings, were determined to be assessed based on their existence and spatial location/relation and not on their shape and dimensions. In B2 these components were 16 -living room window west 2nd floor and 18 -kitchen window (Figure 12 and Table 2) and in B1 it was component 20 -the fireplace (Figure 13 and Table 3). The material composition of the building components were not the focus in this analysis because they were not specified in the drawings except for three of the components in B2. These three components were 4 -the study room wall, 6 -the stair block and 7 -the balcony block (Figure 12 and Table 2).

In the drawings these components having solid parapet walls were clearly depicted and were playing an important role in defining image of the building mass in 3D. Yet it was seen that it were these 3 components in depiction of which most participants altered their solid appearance and depicted the parts of the walls that function as parapet walls as railings. For these three components, the material property included as a third sub-category under the characteristic of shape.

The following section provides a brief overview of how each building component was evaluated based on the identified categories and how the components that did not

belong to the building but that were added to the composition by the participant were taken into account in the assessment of their drawings. It then describes how the results of the evaluation were converted into points for calculation of the performance scores.

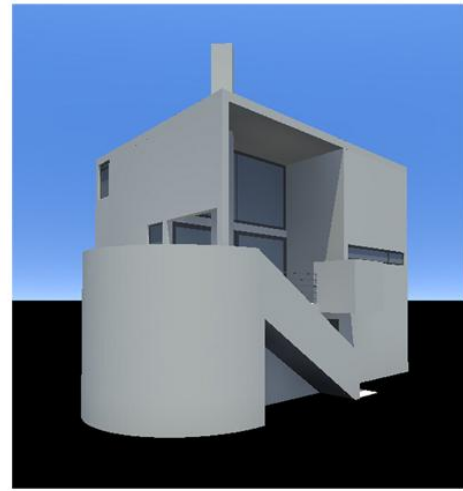
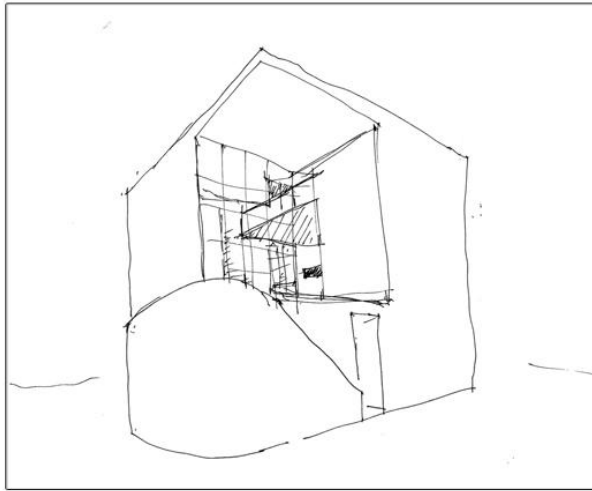


Figure 14 Participant A11's drawing of B2 and a similar view taken from the model

Table 2 Evaluation scheme of exterior view of B2: participant A11

Participant: A11								
Num	Component Name	Inc.	Exist.	Form Properties			Spatial Location	
	Building Components							
1	Angular wall	N	NA	Shape NA	Dim. NA		NA	
2	Living room west wall	Y	1	Shape -	Dim. -		1	
3	Terrace column	Y	-	Shape -	Dim. -		-	
4	Curved study room wall	Y	1	Shape 0.4	Dim 0.3	Mat 0.3	1	
5	Study room-south wall	Y	1	Shape 0.5	Dim. 0.5		1	
6	Stair block	Y	1	Shape -	Dim -	Mat -	1	
7	Balcony block	Y	-	Shape -	Dim -	Mat -	-	
8	Service core west wall	Y	1	Shape 0.5	Dim. 0.5		1	
9	Service core south wall	Y	1	Shape 0.5	Dim 0.5		1	
10	Canopy	Y	1	Shape 0.5	Dim. 0.5		1	
11	Living room south wall	Y	1	Shape 0.5	Dim. 0.5		1	
12	Chimney	Y	0	Shape 0	Dim. 0		0	

Table 2 Continued

Num	Component Name	Inc.	Exist.	Form Properties		Spatial Location
13	Skylight triangular mass	N	NA	<i>Shape</i> NA	<i>Dim.</i> NA	NA
14	Cylindrical stair block	N	NA	<i>Shape</i> NA	<i>Dim.</i> NA	NA
15	Terrace railing	Y	1	<i>Shape</i> 0.5	<i>Dim.</i> 0.5	1
16	Living room window west 2 nd floor	Y	-	<i>Excluded</i>		-
17	Living room window west 1 st floor	Y	-	<i>Shape</i> -	<i>Dim.</i> -	-
18	Kitchen window	Y	-	<i>Excluded</i>		-
19	Living room south wall window 1 st floor	Y	0.6	<i>Shape</i> 0.3	<i>Dim.</i> 0.3	0.6
20	Living room south wall window 2 nd floor	Y	0.6	<i>Shape</i> 0.3	<i>Dim.</i> 0.3	0.6
	Nonexistent components					
	Score: 28.6/43.8x100 = 65.29					
	Maximum Points to be collected (P-Max): 43.8		Total Points collected (P-Col): 28.6			

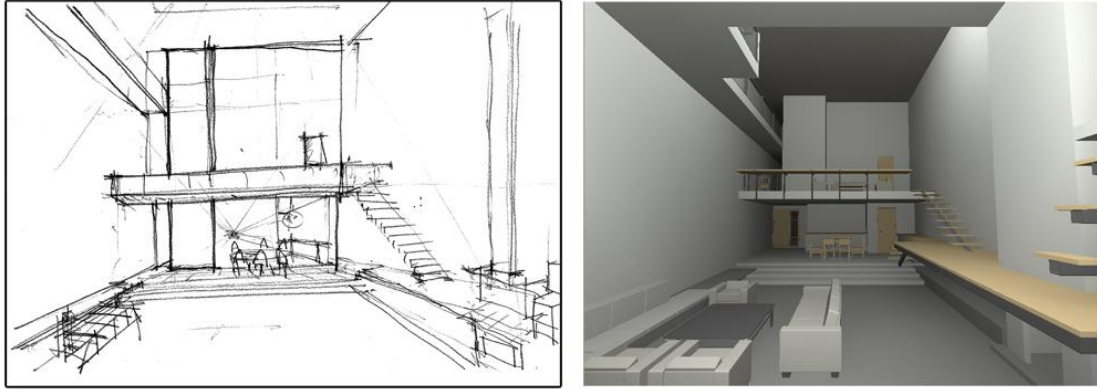


Figure 15 Participant A4's drawing of B1 and a similar view taken from the model

Table 3 Evaluation scheme of interior view of B1: participant A4

Participant: A4						
Num	Component Name	Inc.	Exist.	Form Properties		Spatial Location
	Building Components					
1	Living room main stair	Y	1	Shape	Dim.	1
				0.5	0.5	
2	Living room surrounding platform right	Y	1	Shape	Dim.	1
				0.5	0.5	
3	Stair first leg from dining	Y	1	Shape	Dim.	1
				0.5	0.5	
4	Raised platform-stair landing	Y	1	Shape	Dim.	1
				0.5	0.5	
5	Stair second leg to balcony	Y	1	Shape	Dim.	1
				0.5	0.5	
6	Living room surrounding platform left	Y	1	Shape	Dim.	1
				0.5	0.5	
7	Door/opening to corridor 1 st fl.	Y	1	Shape	Dim.	1
				0.5	0.5	
8	Dining area recessed back wall	Y	1	Shape	Dim.	1
				-	-	
9	Kitchen area protruding wall	Y	1	Shape	Dim	-
				0.5	0.5	
10	Door/opening to kitchen area	Y	1	Shape	Dim.	1
				-	-	
11	Balcony slab with railing (of any kind)	Y	1	Shape	Dim.	1
				0.5	0.5	
12	Opening to 2 nd floor corridor	Y	1	Shape	Dim.	1
				0.5	0.5	
13	Protruding wall sauna, mechanical room 2 nd and 3 rd fl.	Y	1	Shape	Dim.	1
				0.5	0.5	

Table 3 Continued

Num	Component Name	Inc.	Exist.	Form Properties		Spatial Location
14	Wall bathroom, mechanical room 2 nd and 3 rd floors	Y	1	Shape	Dim.	1
				0.5	0.5	
15	Door/opening to dressing room	Y	1	Shape	Dim.	1
				0.5	0.5	
16	Opening to 3 rd floor corridor	Y	1	Shape	Dim.	1
				0.5	0.5	
17	Bridge	Y	1	Shape	Dim.	1
				0.5	0.5	
18	North wall	Y	1	Shape	Dim.	1
				0.5	0.5	
19	South wall	Y	1	Shape	Dim.	1
				0.5	0.5	
	Other Components					
20	Fireplace	Y	1	Excluded		1
21	Walls surrounding chimney	Y	1	Shape	Dim.	1
				0.5	0.5	
22	Ladder	Y	1	Shape	Dim	1
				0.5	0.5	
23	Raised platform to green house (VD*)	Y	1	Shape	Dim.	1
				NA	NA	
24	Guestroom slab (VD*)	Y	1	Shape	Dim.	1
				NA	NA	
25	Bridge-guestroom corner slab	N	NA	Shape	Dim.	NA
				NA	NA	
	Nonexistent Components					
	Score: 66/69x100 = 95.65					
	Maximum Points to be collected (P-Max): 69		Total Points collected (P-Col): 66			
VD* indicates that the participant’s visualization of this component was derived from the verbal description of the view and incorporated into the grading afterwards (as discussed in the following section).						

3.1.2 Assessment of the Drawings Based on the Developed Evaluation Schemes

As a result of the procedure followed for identification of the building components to be included in analysis of each participant's drawings, 2 participant-specific evaluation schemes were developed for assessment of each participant's drawings of 2 views. In the evaluation process, any building component which was included in analysis and which was incorporated in the participant's drawing regardless of accuracy of its form and spatial location, was considered as an existing element and was marked with a check mark. Each existing element was then evaluated based on three categories, and were marked with a check mark in the case it was found to be accurate. In the context of this analysis, the evaluations about the accuracy of the shape and dimension of the component and the accuracy of the component's spatial location/relation were mainly made at a coarse level as follows:

- In evaluating the shape, the building components were examined based on their basic geometry such as being a rectangle planar element, a rectangular prism, half circle or $\frac{3}{4}$ circle with a square corner. For various components particularly in the internally visualized building, the shape information provided in the drawings for some components such as stairs were very abstract, accordingly, as long as a stair is depicted, the shape information was considered accurate.
- Due to distortions in the drawings, as well as different proportioning of components in the depiction of the building, the accuracy of the dimensions of the components were evaluated at a coarse level as relative dimensions rather than absolute. The relative dimensions of a component were defined and determined in relation to other building components where available such as the landing of one-floor height stair to be at the middle of the floor height or closer to the lower level, or a bridge connecting two parts of the building having a narrow width or a wall being shorter than the floor height.

- Spatial locations/relations of building components were evaluated based on the accuracy of their approximate positioning in the overall composition and the neighbor components such as a triangular mass (component 13 in Figure 12) being at the north east corner or the cylindrical mass (component 14 in Figure 12) being on the north side of the building and next to the triangular mass (Figure 12).

After all the participants' drawings were evaluated by putting checkmarks for the existence of the component, for the accuracy of shape and dimensions and in some cases materials, and spatial locations/relations, these checkmarks were then converted into points based on the following schemes.

In the drawings of B2's exterior view, the components were categorized into two groups as primary and secondary building components. The major components that define the building mass such as the walls and columns were considered as the primary components. The components such as the windows and doors were considered as secondary components as they do not define the building mass and therefore it was very likely that the participants did not pay as much importance to them as the primary components in the visualization of this building. Accordingly in converting the checkmarks to the points for the identification of the performance scores of these drawings, the primary components were assigned 1 point and secondary components were assigned 0.6 points for each of the following categories:

- For being existent in the drawing
- For accuracy of its form characteristics; form characteristics accuracy point was equally broken down into 2 or 3 depending on the subcategories included -shape, dimension, and material
- For accuracy of spatial location and relation

In the drawings of the interior space of B1, all the components were assigned with 1 point for each of the above categories.

Calculating the Performance Score

After the evaluation, the total points collected from each drawing were calculated by summing up the points earned for each building component (abbreviated as P-Col.). Then, the scores of the participants were calculated as the percentage of maximum points that would be gained by the participant if all the building components included in the scoring had gained points from all included categories (abbreviated as P-Max). Thus the formula applied was: $(P\text{-Col}/P\text{-Max}) \times 100$.

Taking the Nonexistent Building Components into Consideration

However, both in the drawings of the B1 from the interior, and B2 from the exterior, it was seen that some participants incorporated nonexistent building components to the building composition. These components varied from new masses or windows added to the exterior form of B2 to new platforms, stairs or interior bridges added to the interior space of B1 (such as in Figure 16).

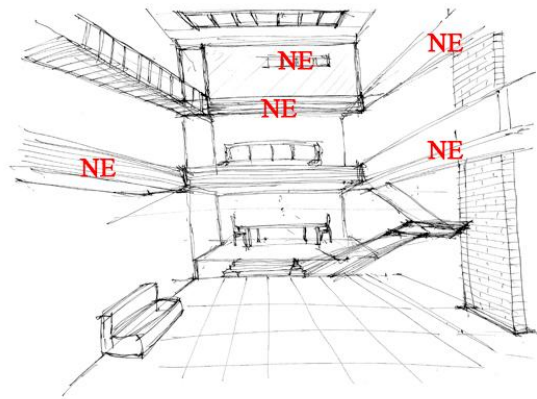


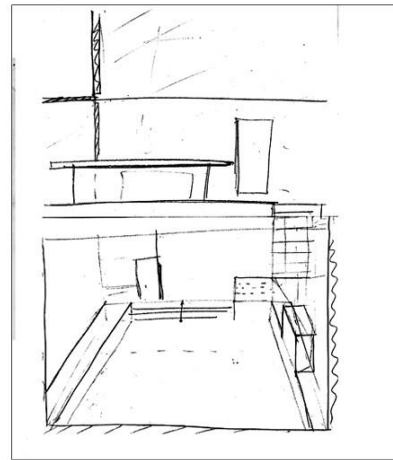
Figure 16 A3's drawing: an example of incorporation of nonexistent (NE) building components

In some cases addition of such components were leading to loss of points when they alter the shapes of the existing components while in some cases not such as adding a nonexistent door or window, or a platform. Through grading the drawings based on the inclusion of existing components, it was possible for two drawings to gain same scores even though in one drawing there were many nonexistent components incorporated to the building's composition. In order to take the inclusion of nonexistent components into consideration in evaluation of visualization performances, clearly discernable components such as additional windows/doors added to the B2's exterior form or new bridges, or stairs, or platforms added to B1's interior space, were incorporated to the participant's evaluation scheme as 'nonexistent components'. These introduced components were incorporated into the calculation of the drawing score as follows.

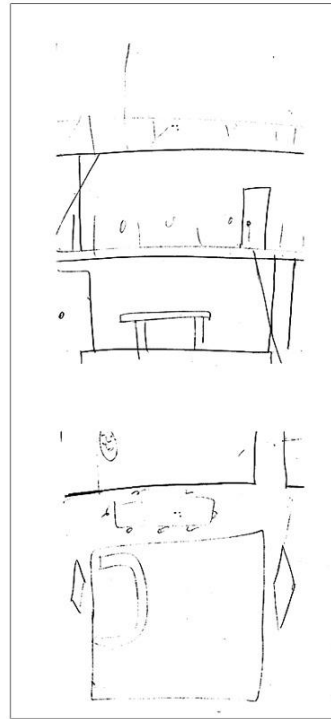
- They were given 0 points for each of the categories -existence, form, spatial location
- The total points that could have been gained from these categories if they had been components that really existed in that building space/form was calculated (abbreviated as P-Intro) and added to the total points that could be earned from the drawing (P-Max).

Accordingly, while the total points that the participant collected from the drawing (P-Col) remained the same, the score of the participant was calculated as the percentage of the points that could have been earned from the drawing (P-Max) and the points that would be earned if the introduced components were existing components (P-Intro). Thus the formula applied for such cases was: $P\text{-Col} / (P\text{-Max} + P\text{-Intro}) \times 100$. For instance, participant A3, whose drawing is presented in Figure 16, collected 40 points from her drawing from the existing components. There were 5 nonexistent components in her drawing; accordingly 15 points as P-intro were added to the P-Max which was 59 points; accordingly her performance score was calculated based on 74 points as $40/74 \times 100 = 54.1$

Overall, performance analyses of the drawings were made by taking into account only the building information contained in them to examine i.e. whether the participants' could capture all the building components in the depicted portion of the building space/form and they could accurately capture the components' shapes, dimensions and spatial locations in 3D space/form. Accordingly, in this analysis, the qualitative characteristics of the drawings were not taken into account such as (1) their being legitimate perspective projections of that building space or form depicting that space/form as would be seen by the eye from the given viewpoint location or being drawings which incorporate both 2D and 3D components, (2) their being generated from an altered viewpoint location such as participant's looking at the space from a bird eye's view or a worm eye view. For instance some participants as can be seen in the examples in Figure 17, have drawn using 2D and 3D methods together in their drawings, which is widely seen in mechanical engineering participants. In such cases, the information about the component shapes, dimensions and spatial locations intended to be conveyed through these depictions was derived in relation to the whole context, sometimes from multiple drawings when necessary and granted points accordingly. While such qualitative characteristics were not taken into account in analyzing the drawings towards identifying performance, they were examined in the architecture participants' drawings in the context of the analyses conducted to understand the nature of the mental representations that architects created during their visualization processes as will be outlined in Chapter 5.



M2's Drawing



M1's Drawing

Figure 17 Examples of the drawings where the participants' depicted their visualizations by integrating 2D and 3D techniques

3.1.3 Assessment of Drawings by an External Reviewer

An external reviewer was requested to evaluate the participants' drawings of the visualized building compositions based on the evaluation schemes that had been developed. The reviewer was first required to familiarize himself with the building designs in 3D, and the views that would be evaluated in the drawings. Then, he was provided with (1) the drawings and the corresponding evaluation schemes developed for each participant, (2) the computer generated corresponding views of the buildings. He was informed about (1) how the inclusion of the components was determined by looking at the participant's drawing and identifying the components that would reasonably be depicted in the drawn view and (2) what level of detail and accuracy was being sought for in evaluation of each building component with regard to the established categories of

evaluation. Accordingly he was requested (1) to evaluate the set of components included for assessment of each participant's drawing and indicate any disagreement on the evaluation scheme and (2) evaluate the resulting list of components by putting a checkmark if the component exists in the drawing and is accurately depicted in the identified categories.

Then his evaluation was compared to the evaluation made by the experimenter to identify the percentage of agreement between the two reviewers. Overall, %100 agreement was found between the reviewers on the components to be included in the evaluation of each of the participants' drawings. Table 4 and Table 5 present the percentages of agreement among two reviewers that were calculated by comparing each reviewer's evaluation of the building components under the categories. As can be seen in the tables, the percentage of agreement between the two raters in their evaluation of each participant's drawings was found to be higher than % 85. The percentage of overall agreement (calculated based on the sum of total number of evaluated categories in each participant's drawing) in evaluation of B1's drawings was found to be % 93.9 and that of B2 % 96.15. After the reliability analysis, the disagreements were reconciled by the consensus of both raters, and the final scores of the participants were determined accordingly.

Table 4 Agreement between the raters in the assessment of the participants' drawings of B1 from the interior

Participant	Num. of components	Num. of evaluated categories	Num. of categories agreed	Percentage of agreement
A1	25	98	95	96.9
A2	21	82	74	90.2
A3	22	86	78	90.7
A4	23	90	84	93.3
A5	22	86	83	96.5
A6	22	86	84	97.7
A7	22	86	76	88.4
A8	21	82	81	98.8
A9	23	90	81	90.0
A10	22	86	81	94.2
A11	23	90	90	100.0
A12	20	80	79	98.8
A13	21	82	78	95.1
M1	21	82	76	92.7
M2	21	82	73	89.0
M3	21	82	74	90.2
M4	21	82	74	90.2
M5	21	82	82	100.0
M6	19	76	71	93.4
M7	21	82	75	91.5
		Total :1692	Total : 1589	Overall: 93.9

Table 5 Agreement between the raters in the assessment of the participants' drawings of B2 from the exterior

Participant	Num. of components	Num. of evaluated categories	Num. of categories agreed	Percentage of agreement
A1	20	77	76	98.7
A2	20	77	75	97.4
A3	21	81	79	97.5
A4	20	77	73	94.8
A5	21	81	80	98.8
A6	21	81	78	96.3
A7	21	81	73	90.1
A8	20	77	74	96.1
A9	21	81	78	96.3
A10	20	77	74	96.1
A11	18	69	68	98.6
A12	21	81	75	92.6
A13	20	77	75	97.4
M1	21	81	80	98.8
M2	21	81	76	93.8
M3	21	81	77	95.1
M4	21	81	78	96.3
M5	21	81	80	98.8
M6	21	81	80	98.8
M7	21	81	74	91.4
		Total: 1,584	Total: 1,523	Overall: 96.1%

3.2 Analysis of the Verbal Descriptions of the Drawn Views

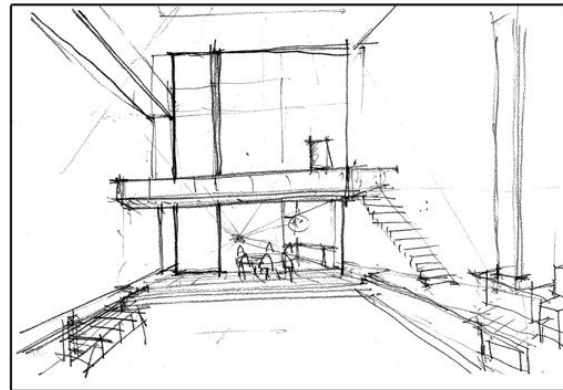
After the drawings were evaluated, the participants' verbal descriptions of the drawn views were examined on the basis of the same evaluation scheme developed for the assessment of their drawings of those views. The purpose of this analysis was to identify any additional building component that the participants could have defined in their verbal descriptions of their visualizations of B1's interior space and B2's exterior form but had not depicted in their drawings. In the context of their verbal descriptions most participants conveyed information about the building components by two different means: speech and the accompanying gestures. They defined the building components in speech and depicted their locations in space and/or their forms (shapes and/or dimensions) through the gestures they produced along the speech; this was why both the verbal utterances and the gestures produced by the participants during their verbal descriptions were closely examined in order to find out any additional component defined and to derive any further form or location information provided about that component.

This analysis was conducted by (1) preparing written transcripts of the participant's descriptions of the drawn view and (2) incorporating the information derived from the gestures about the component locations and/or form properties in to these transcripts. As can be seen Table 6, the information derived from the gestures were incorporated into written transcripts by putting them in parenthesis next to the piece of speech they accompanied and underlining this piece of speech. Then the components defined in the written transcripts were reviewed in comparison to components included and assessed in evaluation schemes of the respective drawings in order to find out if any additional components were defined in the verbal descriptions of the drawn view. As can be seen at the last row of the Table 6, the additional components found in the verbal description were then noted separately under the written transcript.

Table 6 Analysis of the information rendered in participant A4's verbal description of the drawn view

A4's verbal description of the drawn view (on the right) prior to generation of the drawing:

That's is a nice view I think, because you get to see aaa...I don't know it's the guestrooms (located over the head); a room it's well above (high above -over the head at a far distance - full arm height) so it's not really close to you anyway (it is above). But probably you get to feel something there (the guestroom slab is a horizontal surface covering above; represents the distance that the slab of the guestroom above continues in the forward direction and that at that front end of the guestroom slab lies a bounding wall that looks towards the gallery space). But it's way up in this space (located above at a distance – full arm height); but it's nice I guess



A4's drawing of Building 1 from given location

that you get to see that, aaa (a floor surface in front that continues at a lower level until a distance forward). You have this stairs there (the stair is located where the sunken floor ends, it is a longitudinal rectangular stair with a couple of steps climbing up to forward direction) like three steps (three steps stacked on top of each other) that (the stair goes up in the forward direction) you walk up (walking on the steps up in forward direction); leave this hole, sink or sunk space (this space has a rectangular shape - with two bounding surfaces on right and left); pass that (behind that -the sunken space) still you have some room where the dining table is (the floor surface of the dining area which continues until a certain distance in forward direction) and you see part of the kitchen probably (a vertical surface located on the forward right) and the corridor where you just walked in (the corridor is located on the left side on the continuation of bounding surface on the left –wall). I guess, well yes, that (an upper location at his right back) you have the green house on your back (located at his direct back) and the door to it (the door is located above at his right back) and then the.. there is the firewall (firewall continues vertically to up its shape has 90 degrees corner -indicating rectangle -it is located on right side a little bit forward to him) and these crazy steps (steps are located to slightly forward of his left climbing toward up almost with a 90 degrees angle), large steps (actual distance between two steps) that take you to the other door (located above at his right back) once you (climb up -climbing up takes place on forward right); yes you have to climb three things (climbing toward him on his right forward -representing steps from the dining area) and you are in the platform (a horizontal flat surface with a long span -platform is represented as he is facing the platform) and then you climb (from the right end of the platform toward up)and then get in there (the raised platform to the greenhouse -after you climb up you turn right and continue walking toward right) but... aaaa what you get to see; I like that you see the floor that is sunken (the floor goes down) and then it comes up (floor continues at the low level to a certain distance and then the floor level rises) and still you have some (space that continues forward to a distance at the higher floor level) distance (relative distance of the described space) where the table is (table is a rectangular table) and what else, aaa, that you see the stairs going up (there is a vertical rectangular longitudinal surface continuing in the front above from left of the space to right of the space and the stairs, which are moving from bottom to up in the forward direction toward that surface, are connecting to it at its right end) the railing there (a longitudinal rectangle located forward above continuing from left of the space to right of the space) andddd aaaa (depicting a vertical surface parallel to him in the forward direction and continuing towards up). Yee I don't remember if the wall that's beneath dining room (a rectangle shown on the table top), the dining room (the wall is located on the left behind the dining area), makes the sauna (sauna is located one floor above) and other part of the bathroom upstairs (bathroom is located on the right of the sauna -wall bounds the sauna area in the upper floor and also the bathroom next to it) plus the machine room (located one floor above the sauna-bathroom area),

Table 6 continued

<p><u>if it's all the way up</u> (representing the shape of the wall as a rectangular prism continuing from bottom-table surface to upper levels) <u>shaped in the same way</u> (the shape is represented as a surface on the forward left continuing to a certain distance to the right at the same plane and then immediately recessing back forming a recessed surface on the forward right). I think it , it must be, so you get to see <u>this shape there</u> (re-represents the previous surface form) plus the railing (a longitudinal rectangle located forward above continuing from left of the space to right of the space) and soo that's pretty much what you see, I am focusing now on <u>this ground floor</u> (located in front of me) because that's probably standing from in there (the given location in the drawing) that's <u>the most immediate thing</u> you get to see (at the front) , but aa, yee, <u>you have</u> (the rectilinear stairs, on the right forward, they are moving up towards the front) the stairs <u>that's in there</u> (the balcony level with the railing) and then <u>the wall coming up</u> (a vertical surface continuing to above) and <u>the bridge</u> (located on left side up) probably <u>you get to see some of it up there</u> (a rectilinear longitudinal surface high above on the left continuing from left forward to left back)</p>
<p><i>Additional information conveyed in the verbal description:</i></p> <ul style="list-style-type: none"> - The slab of the guestroom located far above the head, it creates continuous horizontal surface when viewed from below, it continues to a certain distance towards the front, and that it has a bounding wall that separates it from the gallery space - greenhouse located behind - a raised platform on the right spanning between the 'crazy' steps (ladder) and the door to the greenhouse at that level)

If an additional component was defined two different actions were taken depending on whether the additional component was originally identified as included in the assessment of the drawings or not. When the additional component was not identified to be included in the analyses of the drawn view such as the components 23 -raised platform to the green house and 24 -guestroom slab (Figure 13) found in participant A4's description (Table 6), it was added to the evaluation scheme (such as in A4's evaluation scheme in Table 3) by putting Y mark in the 'inclusion' field with an indication that it was derived from the verbal description (VD) and (2) was given a checkmark as an existing component in the 'existence' field. In case further information was provided about the component, such as its shape or spatial location in space, and the information was accurate, a checkmark was also put to the corresponding categories of evaluation. For instance, in the case of participant A4, it was found that the participant provided information about the spatial locations of the additional two components, 23 and 24, and was given checkmarks for the spatial location category as can be seen in Table 3. In these

cases, the categories, with regard to which no information was provided about the additional component, were considered as not applicable (NA) and were not included in the calculation of the P-Max.

Thus the participants basically received additional points for such additional components but did not lose any points due to non-specified information. When the additional component was a component which was originally identified to be included in the assessment of the participant's drawing but was not granted any points due to its not being depicted in the drawing, it was given a checkmark as an existing component in the *existence* field by indicating that it was derived from the verbal description (VD). Likewise, if any further information was provided about this component with regard to its spatial location or shape and the information was accurate, a checkmark was also put to the corresponding categories of evaluation. In the case of categories with regard to which no information was found either in the drawings or in the verbal descriptions, remained the same and included in the calculation of P-Max.

3.2.1 Examination of the Information Conveyed by Gestures by an External

Reviewer:

In this analysis of the verbal descriptions, gestures constituted important source of data conveying substantial information about the components such as their spatial locations and/or shapes among many others. In order to ensure the reliability of the information derived from the gestures in the context of this analysis, an external reviewer was requested to review a number of gestures from each participant's protocol and infer the information conveyed by them. Considering the number of participants and the density of the gestures in their protocols, within the scope of this analysis, it would not be feasible for the external reviewer to examine all the gestures produced by each participant to derive their meanings. Thus, the reviewer was requested to randomly select a minute segment from the video of each participant and to examine the gestures that take place

during this minute to infer the information conveyed by the gesture. Prior to the procedure, the reviewer was provided a written transcript of the participants' speech and requested to underline the portions of speech that was accompanied by the viewed gestures during the one minute segment and note the information derived in relation to the statement it took place. The reviewer was provided with a remote control so that he could stop and take notes after observing each gesture. After this review process, the notes taken by the reviewer was compared to the information derived by the experimenter for identifying reliability of the inferences made by the experimenter. This comparison was made in the presence of the reviewer to account for the possible differences in language in definition of the information derived from the gestures. Based on this comparison it was found that the external reviewer reviewed a total of 137 gestures from 20 participants and the percentage of agreement between the raters was % 100 suggesting that the gesture information derived by the experimenter from the gestures was reliable.

3.3 3D Mental Visualization Performances of Participants

The performance scores identified in this analysis on the basis of the analyses of the drawings by two raters and the analyses of the information that participants' rendered in their descriptions verbally and through gestures are tabulated in the Table 7.

Table 7 Participants' 3D mental visualization performance scores as agreed by both reviewers

Part #	Performance in 3D mental visualization of B1	Performance in 3D mental visualization of B2
A1	76.6	71.4
A2	86.6	79.2
A3	59.8	29.7
A4	94.4	91.8
A5	76.5	71.5
A6	90.8	80.0
A7	66.2	57.4
A8	75.4	68.7
A9	79.9	85.9
A10	90.0	46.7
A11	85.7	63.7
A12	73.8	47.3
A13	78.5	65.3
M1	57.7	39.7
M2	74.2	37.8
M3	39.8	42.2
M4	69.2	58.3
M5	75.4	42.4
M6	40.8	27.3

CHAPTER 4

PERFORMANCE IN 3D MENTAL VISUALIZATION TASKS

This chapter presents and discusses the results of the statistical analyses which were conducted to address the 2nd, 3rd, and 4th questions in this research where 3D mental visualization is investigated as a cognitive capability. The analyses that will be discussed in this chapter include (1) analysis of the performances of architecture and mechanical engineering participants in 3D mental visualization tasks, (2) analysis of the relationship between 3D mental visualization performance, years of work experience and last engagement with design (3) analysis of the performances in interior and exterior 3D mental visualization tasks (4) analysis of spatial visualization abilities of architecture and mechanical engineering participants, (5) analysis of the relationship between spatial visualization ability and 3D mental visualization performance.

4.1 Performances of Architecture and Mechanical Engineering Participants in 3D Mental Visualization Tasks

The obtained interior and exterior visualization task performances and SVA test scores of the participants were analyzed to observe whether there were differences among the group performances. As presented in Table 8, there were differences between group means in all three outcome scores. In the performed t-tests (Table 9) these mean differences were found to be statistically significant indicating that architecture participants ($M = 79.54$, $SD = 9.93$) performed significantly higher than mechanical engineering participants ($M = 62.26$, $SD = 16.41$) in interior visualization task [$t(8.44) = -2.55$, $p < .05$] and architecture participants ($M = 64.04$, $SD = 17.37$) performed significantly higher than mechanical engineering participants ($M = 45.18$, $SD = 13.73$) in exterior visualization task [$t(18) = -2.94$, $p < .05$].

Table 8 Group statistic of mechanical engineering and architecture participants' visualization task performances

Task/Test	Group	Number	Min	Max	Mean	Std Dev	Std Err Mean
Interior Visualization Task	Arch	13	59.76	94.44	79.54	9.93	2.76
	ME	7	39.84	78.68	62.26	16.41	6.20
Exterior Visualization Task	Arch	13	29.65	91.77	66.04	17.37	4.82
	ME	7	27.33	68.41	45.18	13.73	5.19

Table 9 Independent samples t-test comparing architecture and mechanical engineering group mean scores

Task/Test	Mean Difference	Std. Err Dif	t Ratio	DF	Sig. (2-tailed)
Interior Visualization Task*	-17.28	6.79	-2.55	8.44	0.033
Exterior Visualization Task**	-20.85	7.61	-2.73	18	0.013
* unequal variances, ** equal variances					

The architecture participants' better performance in 3D mental visualization tasks might be interpreted in a number of ways. First, there is the possibility of self selection; individuals with high level abilities that underlie these skills, might have had selected to major in architecture or in the same sense, individuals with low level underlying abilities such as mechanical engineering participants might have had avoided majoring in architecture. Second, there is the possibility of educational-selection; while such skills might not be demanded in Mechanical Engineering the demands of architectural design might be making high level 3D mental visualization skills a need for the students as a result of which students with low level 3D mental visualization skills might be dropping out from the school. The third possibility is that the domain specific activities and the training in architectural education and practice, might be enhancing students 3D mental visualization skills while not in mechanical engineering education. Which one of these possibilities holds need be investigated in future research by conducting within-subjects longitudinal studies with larger populations.

Yet, at this point what we know is that demands of both fields make it a need for students to be able to carry out 3D mental visualization activities. We also know that in both domains students through training are expected to develop drawing reading and generation skills i.e. being able to represent and interpret a 3D entity through/from its 2D projection views such as sections, plans and elevations; this constitutes an important skill in the kinds of 3D mental visualization practices that are investigated here. When we consider that these skills are demanded and/or developed in both domains, it becomes reasonable to assume that participants from both groups are the ones selected through education or the ones self selected prior to education. given these similarities between these two fields in terms of involvement of and reliance on 3D mental visualization practices, the question becomes what might account for the differences observed in the studied group of architecture and mechanical engineering participants?

One possible difference in these fields, which might explain the observed differences, could be the extent to which 3D mental visualization activities are carried out or demanded in these fields. In architecture, design constitutes the core of Architectural education to the extent that students have to take a design studio each semester starting from the first year until the graduation. In this respect they are always engaged with designing almost every day. On the other hand, in mechanical engineering, design is generally one component of the many classes they take and only a primary focus in some of the courses. Since architecture participants are more exposed to design activity, they might be carrying out 3D visualization activities more frequently than mechanical engineering participants in the context of their education and practice. In the same respect these activities might be more demanded in architecture than in mechanical engineering. Accordingly, these differences in the demands and exposure might be the cause for the observed differences in the performances.

From the perspective of being exposed to design, one possible cause of the observed difference could also be that the mechanical engineering participants were less

experienced in general when compared to architecture participants in this study. Mechanical engineers who participated in this study had very little work experiences ranging between no experience to 1 year of experience. Whereas architecture participants experience levels ranged between no experiences to 8 years of experience. In order to examine if this might have caused the differences, I identified the architecture participants who have equal to or less than 1 years of experience which formed a group of 4. The average performance of this architecture sub group ($M = 79.87$, $SD = 7.5$) was still higher than the mechanical engineering sub group ($M = 62.26$, $SD = 16.41$) in interior visualization task and their performance in exterior visualization task ($M = 66$, $SD = 6.8$) was also higher than ME ($M = 45.18$, $SD = 13.73$). The differences in interior visualization performances was statistically significant $p < .05$ at one tailed level [$t(9) = -1.9$, $p = 0.038$ (one tailed $H1 = \text{Arch} > \text{ME}$)] and the difference in the exterior visualization task was statistically significant $p < .05$ at two tailed level [$t(9) = -2.3$, $p = 0.039$]. These results suggested the obtained differences among architecture and mechanical engineering participants performance was not due to mechanical engineering participants being less experienced.

In this study, there was one commonality among the mechanical engineering participants; they were not specialized in design of building systems, as was the decisive factor in this study, and they were all specialized in design of small scale entities which can all at once be apprehended from single vantage points. In this study, one of the motivations for investigating the relationship between SVA and 3D mental visualization performances of the participants was my intuition that 3D mental visualization skills of architects, contrary to the general belief, might not be related to spatial visualization ability as determined by the paper-pencil tests. The paper pencil tests of SVA, such as the paper-folding test incorporated in this study involve visualization and manipulation of small scale abstract objects which can be apprehended from a single vantage point. Thus, the scale of the entities that are visualized and manipulated in the tests of SVA bears a lot

of resemblance with that of the entities that mechanical engineers had been dealing with in their design processes and thereby mentally visualizing during their design practices; both were small scale entities that can be apprehended from a single vantage point and that are external to the body. On the contrary the scale of the entities in both were quite different than that of the entities that architects design and mentally visualize during the course of their design practices; architectural design deals with design of building environments which are large scale entities that cannot be apprehended from a single vantage point and whose apprehension requires capturing of sequences of views either by changing the line of sights such a by turning the head around or by locomotion.

My suspicion is that architectural visualization tasks as they involve visualization of large scale 3D environments, which they embody the individual, cannot be apprehended at a glance and require integration of views from multiple viewpoints, might involve abilities and mechanisms that might not be involved in visualization of small scale objects which can be apprehended from a single vantage point. This is why mechanical engineering participants, even though they conduct 3D mental visualization practices in the context of their practices, could have performed less well than architects in the architectural visualization tasks. Such a difference would not only explain the mechanical engineering participants' performing lower than the architects in these 3D mental visualization tasks even though being individuals who carry out 3D mental visualization tasks in the course of their design practices but also would explain why the findings of the studies of spatial abilities in architectural design could not provide a basis for formulating a coherent case in support of the general belief that spatial abilities are crucial abilities for architectural design practice. This difference, as I will discuss further in the upcoming sections, would also explain some of the findings gathered in previous studies and the findings that are obtained in the context of the other analyses carried out in this study. Both this and other plausible explanations for the found differences between

mechanical engineering and architecture participants 3D mental visualization performances need to be investigated by further studies.

4.2 3D Mental Visualization Performances, Years of Work Experience and Years Passed since Last Design

Individual differences were found among the studied group of participants in terms of their levels of performances in the carried visualization tasks. As can be seen in the groups statistics in Table 8, architecture participants visualization performances varied between 59.76 and 94.44 for the interior task ($M = 79.54$, $SD = 9.93$) and between 26.96 and 91.77 for the exterior task ($M = 64.04$, $SD = 17.37$). Mechanical engineering participants visualization performances varied between 39.84 and 78.68 in the interior visualization task ($M = 62.26$, $SD = 16.41$) and between 27.33 and 68.41 in the exterior visualization task ($M = 45.18$, $SD = 13.73$). There might be various factors that might have led to these individual differences in visualization performances within the studied group of participants. In the context of this study, two of the potential factors, were explored to see if they might account for the differences in the participant's visualization performances. These include (1) differences in the participants' years of work experience with the thought that having carried more design projects might have improved the participant's 3D mental visualization skills and (2) the years passed since the participant was last engaged with design with the thought that that no use of these skills for longer periods of time might have decreased participants' visualization performances.

The performed bivariate regression analyses did not show a significant contribution of years of work experience to architecture participants' interior or exterior visualization performances (interior: $R^2 = 0.13$, $p = 0.21$, exterior: $R^2 = 0.05$, $p = 0.44$). No analysis was performed for the mechanical engineering participants years of work experience as there were no salient variations between mechanical engineering participants' work experiences, all mechanical engineering participants work experiences

were less than or equal to one year. The performed regression analyses to investigate the (negative) contribution of not having been engaged with a design project for a certain while to the interior and exterior visualization task performances did not show any significant contribution either, both for the architecture participants (interior: $R^2 = 0.06$, $p = 0.39$, exterior: $R^2 = 0.15$, $p = 0.19$) and mechanical engineering participants (interior: $R^2 = 0.002$, $p = 0.73$; exterior: $R^2 = 0.13$, $p = 0.21$). These results indicate that the individual differences were not related to and could not be accounted for by their years of work experiences in the architecture participants or by the years passed since their last design engagement in both architecture and ME participants.

One other factor that might explain the observed individual differences, at least high or low performances, would be the participants not being able to carry out such 3D mental visualization activities in their design processes. In their interviews, participants were asked whether they carry out such 3D visualization activities in their design. All participants responded to this question positively, pointing that they (think that they) do visualize their design in 3D in their minds while designing and there were no indication that some were having difficulty in doing so. On the other hand, there might be differences in the extent to which each participant do conduct or rely on mental visualization activities; and this might have lead to differences in participants performances. At this point, since some participants were more explanatory in their interviews while others were not, such information is not available for all participants. This information needs to be acquired and integrated in the conducted future studies.

4.3 Performances in Interior and Exterior 3D Mental Visualization Tasks

The visualization tasks conducted in this study were very similar in terms of they both requiring visualization of a building composition based on its 2D drawings. The differences between them were that (1) exterior visualization task involved two section drawings for providing building information while interior visualization task involved

only one section drawing, (2) exterior visualization task involved a more complex organization of forms in 3D when compared to the interior visualization task and (3) exterior visualization task required visualization of the appearance of the building's composition from the exterior while interior visualization task required visualization of the building's interior spaces and the elements within. The first two differences might have yielded to better performance outcomes in the interior visualization task than the exterior visualization task. On the other hand, the performances of the individuals in these two tasks should highly relate due to similarities in these tasks with only difference being the building visualized from exterior or interior, which, might call for different strategies and mechanisms that we do not yet know of and result in lack of strong correlations. These two issues were examined by observing the individual's respective interior and exterior visualization scores and by looking at the correlations between performances in these tasks. The close observation of the resulting performances, as in Figure 18, indicated that except for two participants, one from architecture and one from mechanical engineering, all participants had performed better in the interior visualization task than the exterior one. The performed linear correlation analyses showed a significant correlation between the participant's interior and exterior visualization task performances ($R = 0.71$ $p = 0.0004$) suggesting a strong relation between them.

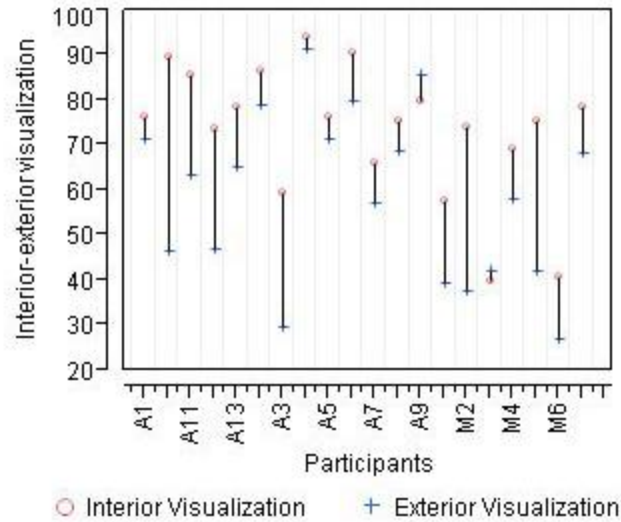


Figure 18 Overlay plots of participant's interior and exterior visualization task performances

4.4 Spatial Visualization Abilities of Architecture and Mechanical Engineering

Participants

The obtained paper folding test scores of the participants as a measure of their spatial visualization abilities were analyzed to observe whether there were differences among performances of architecture participants and mechanical engineering participants. As presented in Table 10, mechanical engineering participants average scores ($M= 17.57$, $SD = 2.14$) were higher than architecture participants ($M= 14.52$, $SD = 3.55$). The performed t-test (Table 11) indicated these mean differences to be statistically significant [$t (17.62) = -2.39$, $p<.05$] and showed that the mechanical engineering participants spatial visualization abilities were significantly higher than that of architecture participants.

Table 10 Group statistic of mechanical engineering and architecture participants SVA test scores

Task/Test	Group	Number	Min	Max	Mean	Std Dev	Std Err Mean
Paper Folding Test (SVA)	Arch	13	8.8	20	14.52	3.55	0.99
	ME	7	14.4	20	17.57	2.14	0.81

Table 11 Independent samples t-test comparing Architecture and Mechanical engineering group mean scores

Task/Test	Mean Difference	Std. Err Dif	t Ratio	DF	Sig. (2-tailed)
Paper Folding Test (SVA)	3.05	1.28	2.39	17.62	0.028*

The mechanical engineering participants having higher spatial visualization abilities than architecture participants might be interpreted in a number of ways. First, this difference could result from occurrence of self selection when choosing majors; individuals with highest level spatial abilities might be selecting to major in mechanical engineering while spatial visualization ability might not constitute important self selection criteria for majoring in architecture. It could also be possible be a result of domain specific needs; mechanical engineering education might be demanding high levels of spatial visualization ability leading to less capable students dropping out from mechanical engineering education whereas architecture education might not. This difference could also be a result of educational improvement; mechanical engineering education might be improving spatial visualization abilities of the students while architecture might not.

So far, there have been two studies (Ho 2006; Yukhina 2007) which looked at the relation between year in study and spatial visualization ability in architecture but as discussed in Chapter 1, their findings were different based on which a conclusion cannot be derived about this relation in architecture. Yet, Ho (2006) in his study found a positive correlation between mechanical engineering students' spatial visualization ability scores

and their year in school and suggested that mechanical engineering education might be improving students' spatial visualization abilities, and engineering drawing classes might be making a significant contribution to this outcome. Both Ho's finding on the improvement of spatial visualization abilities through education and the other possibilities that are outlined above can only be investigated and clarified by carrying longitudinal within subject studies.

Previously, I underlined that the mechanical engineering participants' performing low in the 3D mental visualization tasks in this study although carrying out 3D visualization practices in their own design processes could be an outcome of architectural visualization dealing with large scale entities might be relying abilities and processes that are not involved in visualization of 3D small scale entities. This could also explain the finding obtained here in that mechanical engineers could have obtained higher scores from the SVA test employed in this study as both involves visualization of small scale entities. In the same line of thought, architects could have scored significantly lower than mechanical engineering participants as they mostly deal with design and visualization of large scale entities. This would explain Akin's (2003) finding that as the years of advance, students of architecture become less efficient in their skills in manipulating small scale 3D rectangular blocks. Akin defined this finding as surprising and seeking for a plausible explanation he suggested that this might be a result of the "training that redirects the students skills away from the spatial reasoning tasks of this kind" or a "dulling" effect of spatial reasoning skills with simple objects due to lack of practice" (pg.16). Akin's finding can be interpreted as an outcome of architects' dealing with design of large scale building environments rather than small abstract manipulable objects and thereby advancing in certain set of spatial skills supporting design of large scale environments rather than simple small scale objects. In the same respect, the mechanical engineering participants' in this study mostly dealing with design and

visualization of small scale objects have advanced their respective spatial skills but not the ones that are involved in visualization of large scale entities such as buildings.

4.5 Spatial Visualization Ability and 3D Mental Visualization Performances

One of the objectives of this study was to investigate the relation between participants' performance in the 3D mental visualization tasks and their spatial visualization abilities as measured by paper folding test. These relations were explored by examining the scatter plots of participants interior and exterior visualization performances in relation to SVA test scores (Figure 19) and performing bivariate correlation/regression analyses on the architects, mechanical engineering and all participants' outcomes. The close examination of the scatter plots did not show any discernable patterns of distributions that could suggest a correlation, linear or non-linear, between paper folding test scores and the 3D mental visualization task scores. The results of the correlation/regression analyses (as summarized in Table 12) did not show any bivariate correlation (that reaches to a statistical significance) between 3D mental visualization task performances and the paper folding test scores. This indicated that the 3D mental visualization performances of the participants were not be related to and could not be predicted by their spatial visualization abilities as measured by the paper folding test.

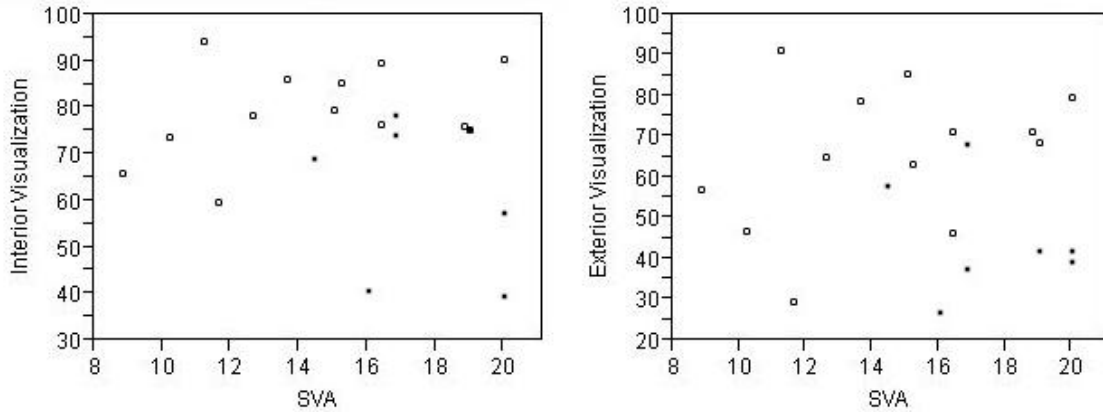


Figure 19 Scatter plots of participants' interior and exterior visualization performances in relation to their SVA scores

Table 12 Correlations between spatial visualization ability and 3D mental visualization performance

Variable	All Participants	Architects	Mechanical Engineers
Interior Visualization & SVA	$R = -0.15$ $R^2 = 0.02$ $F = 0.41$ $sig. prob. = 0.53$	$R = 0.36$ $R^2 = 0.13$ $F = 1.65$ $sig. prob. = 0.22$	$R = -0.27$ $R^2 = 0.07$ $F = 0.39$ $sig. prob. = 0.56$
Exterior Visualization & SVA	$R = 0.09$ $R^2 = 0.00$ $F = 0.13$ $sig. prob. = 0.71$	$R = 0.32$ $R^2 = 0.1$ $F = 1.22$ $sig. prob. = 0.29$	$R = -0.28$ $R^2 = 0.08$ $F = 0.43$ $sig. prob. = 0.54$

There might be a number of explanations for the observed lack of relation between SVA and performance in 3D mental visualization tasks. First, it could be the result of participants applying non spatial strategies in solving the problems in paper folding test resulting in the test tapping abilities in addition to or other than the spatial visualization ability. As discussed and reported by various researchers (e.g. Just and Carpenter 1985; Lohman 1988; Gluck and Fitting 2003), participants might employ different strategies when solving spatial tasks. In the paper folding task, one could employ an analytic or a visualization strategy or mixture of both depending on the difficulty of the test item (Kyllonen, Lohman et al. 1984). Although, this would be one extreme, that is to say, it has a very little chance to occur in all participants, some

participants could have employed analytical strategies or mixed strategies in the paper folding test; this might have led to measurement of other factors by the paper folding test in addition to or other than the spatial visualization ability leading to the observed lack of correlation between the participants' SVAs and 3D mental visualization performances. Second explanation for could be the existence of a threshold in the level of spatial visualization ability that is required to carry out the 3D visualization tasks and this threshold might be lower than the one that architecture and mechanical engineering participants had. Similarly, the small range of the mechanical engineering participants SVA scores might have prevented observation of the possible correlation of their spatial visualization ability and 3D mental visualization scores. Another explanation could be that spatial visualization ability might indirectly be related to the 3D visualization performances in that it might underlie a component process which cannot be discerned at this direct level of analysis.

From a statistical point of view, not finding a significant correlation between participants' 3D mental visualization performances and spatial visualization abilities could be attributed to the small size of the studied population. This could be a possible explanation in case the scatter plots showed a relation but this relation was not statistically significant. Yet, in this case, this seems to be unlikely as the scatter plots show no relationship between the spatial visualization performances and the spatial visualization abilities of the participants.

The last explanation for the observed lack of relationship could be that 3D mental visualization tasks in architecture require abilities different than or in addition to spatial visualization ability. A further explanation to this as I have been outlining in this chapter could be that the mental visualization of large scale and small scale entities implicate different set of underlying abilities and mechanisms. The findings from some studies in spatial abilities provide some evidence in support of such differences. One such finding is the relationship found between SVA and performance in mental simulation of mechanical

systems where the mental simulated systems are conveyed through small scale depictions of these systems such as a system of pulleys, or a pair of gears (Hegarty and Sims 1994; Hegarty and Steinhoff 1997). Another finding is the improvement in SVA was after the first year engineering graphic course where the students were trained with mental cutting activities involving small scale objects (Field 1999; Németh 2007). Some evidence in support of the view here comes from studies of the relationships between spatial abilities as measured by the paper pencil tests involving small scale stimuli and performance in large scale spatial tasks; so far performance in large scale spatial tasks such as way finding and environmental learning have been found to weakly correlate or to be partially associated with SVA (e.g. Hegarty, Richardson et al. 2002; Hegarty, M., D. R. Montello, et al. 2006; for a review see Hegarty and Waller 2005).

CHAPTER 5

ANALYSIS OF ARCHITECTURE PARTICIPANTS' 3D MENTAL VISUALIZATION PROTOCOLS

This chapter discusses the outcomes of the analysis conducted on the gestures that architecture participants produced during their 3D mental visualization processes in the various 3D mental visualization tasks in this study. The aim of this analysis was to develop an understanding about the features of the architects' 3D mental visualizations in the various tasks and the nature of the mental representations that were created during these visualization processes.

The 3D mental visualization tasks in this study mainly required the architecture participants (hereafter called 'participants'), to study the 2D plan and section drawings of two buildings individually with the aim of visualizing the interior spaces of the first building, B1 and the exterior form of the second building, B2, and carrying out a series of visualization tasks and generating the drawings of some of the visualized views after the study session. These tasks were mainly of two types with regard to the conditions under which the architects were asked to visualize the buildings' space(s)/form: they were requested to visualize the buildings' space(s)/form either by imagining themselves standing at a given location or walking inside/outside the building. In the first task, which here after will shortly be referred to as task #1-B1-W (W for imagining walking), the participants were asked to visualize and describe the appearance of the various interior spaces of the B1 by imagining themselves walking through them; they were not given a specific path to follow. In the second task, which hereafter will be referred as task #2-B1-S (S for imagining standing), participants were shown Location 1 on an empty plan of the first floor of the B1 and asked to visualize and describe the appearance of the gallery

space by imagining themselves standing at that location in a specified orientation. In the third task, which here after will be referred to as task #3-B1-S, they were shown another location, location 2, on an empty floor plan of the ground floor of B1 and asked to visualize and describe the appearance of the gallery space by imagining themselves standing at that location in a specified orientation; after the description they were requested to draw their visualizations of this space from this location. In the fourth task, which here after will be referred to as task #1-B2-S, they were shown Location 1 on a symbolic footprint of B2 on the site and asked to visualize and describe the exterior form of B2 by imagining themselves standing at that location in a specified orientation; then they were requested to draw their visualizations of the building from this location. In the last task, which here after will be referred to as task #2-B2-W, the participants were shown clockwise direction on the symbolic footprint of B2 and asked to visualize and describe the exterior form of B2 by imagining themselves walking around the building in this direction starting from their most recent location -Location 1.

The first section of this chapter outlines the ways, in which the participants were observed to be visualizing the building in their imaginations, in the analyses of their visualization protocols across the various visualization tasks. The second section provides a synopsis of the patterns of forms of visualization observed in these participants' visualization processes within each of the visualization tasks and discusses the inferences that were made with regard to the features of their 3D mental visualizations as evidenced in each of these various 3D mental visualization tasks. The third section outlines the overall understanding attained in this analysis with regard to the nature of the mental representations that participants creating during their 3D mental visualization processes. The last section discusses the issue of the differences between 3D SS and 3D LS visualization that came to attention in the context of this analysis.

5.1 Forms of Visualization

5.1.1 Forms of Visualizations across All Tasks

As discussed in the previous chapters, the participants produced a considerable amount of gestures in the context of their verbal descriptions of their visualizations. Each gesture when examined as single unit provided information about the spatial locations or shapes of the components or arrangement of spaces. However, when they were examined in sequence they were rendering a common underlying representation of the building. In close examination of the sequence of the gestures in all the visualization tasks, participants' were observed to be visualizing the building spaces and forms in one or more of the following three forms in each visualization task.

Form 1- Visualizing the 2D Layout of the Building in Small Scale:

While describing their imaginings of walking inside B1, some participants were pointing to or putting their hands to different locations, drawing some invisible lines or 2D shapes on the table surface or on an invisible horizontal plane in the air as if they drawing, or referring to, an invisible small scale 2D layout of that portion of the building and imagining that portion of the layout in 2D scale. In these cases, the rendered 2D layout of the floor or a portion of the floor was 3 to 4 times larger than the relative size of the floor layouts in the given drawings. Figure 20 presents an example of such an occurrence where a participant was rendering the 2D layout—while imagining walking inside B1.



Figure 20 Participant's depiction of a portion of the floor layout in 2D. Here the participant was mainly depicting the relationship between the bathroom space at **1** and the corridor which extends starting from **2** toward **3** in a longitudinal rectangle form. In the first two snapshots on the left the participant was depicting the relative location of the bathroom and the form of the corridor by sweeping her right hand from position **2** to **3**. In the three snapshots towards left the participant was mainly depicting how the walking path is bounded when walking from **a** towards **b** and then towards **c** -the bridge area.

Form 2- Visualizing a Small Scale 3D Model of the Building or a Portion of the Building

While describing their visualizations, some participants simultaneously rendered an invisible small scale (SS) 3D model of the building or the portions of the building in their gesture spaces as if they were imagining a 3D SS model of that building or building portion at the time. These invisible models were much like physical SS models of the buildings or portions of the building with a scale of around 1/20 meters. In some instances, their highest points were approximately at eye level with the lowest level resting on the surface of the table while in others their highest points were above the eye level with their lowest level hanging 3-6 inches above the table surface. Figure 21 and Figure 22 represent some snapshots from two participants who were observed to be visualizing the 3D layout of the building spaces in the way these spaces would be in a 3D SS model in task #1-B1-W. The participant in Figure 21, during her visualization process was mainly rendering the 3D SS model of the B1 by depicting the 3D layout of the

spaces at different portions of the building. Participant in Figure 22 was mainly rendering a 3D SS model of B1 by depicting the 3D layout of the spaces in the order that each space would be encountered on a walk path. Here the participant, as generally observed in some other participants, as he came to the point to depict the components that would be at the other end of his gesture space and out of his reach in his current position, depicted those components at the furthest point he further away could reach in his gesture space. Such cases were much like moving a SS model of the building closer to reach to the further end. In such cases, the models that participants rendered in their gesture space were interpreted as coherent models of the overall building form. Figure 23 presents some snapshots from a participant's visualization of the southwest corner of B2 from the exterior where he was observed to imagining a 3D SS model of the southwest corner of B2.

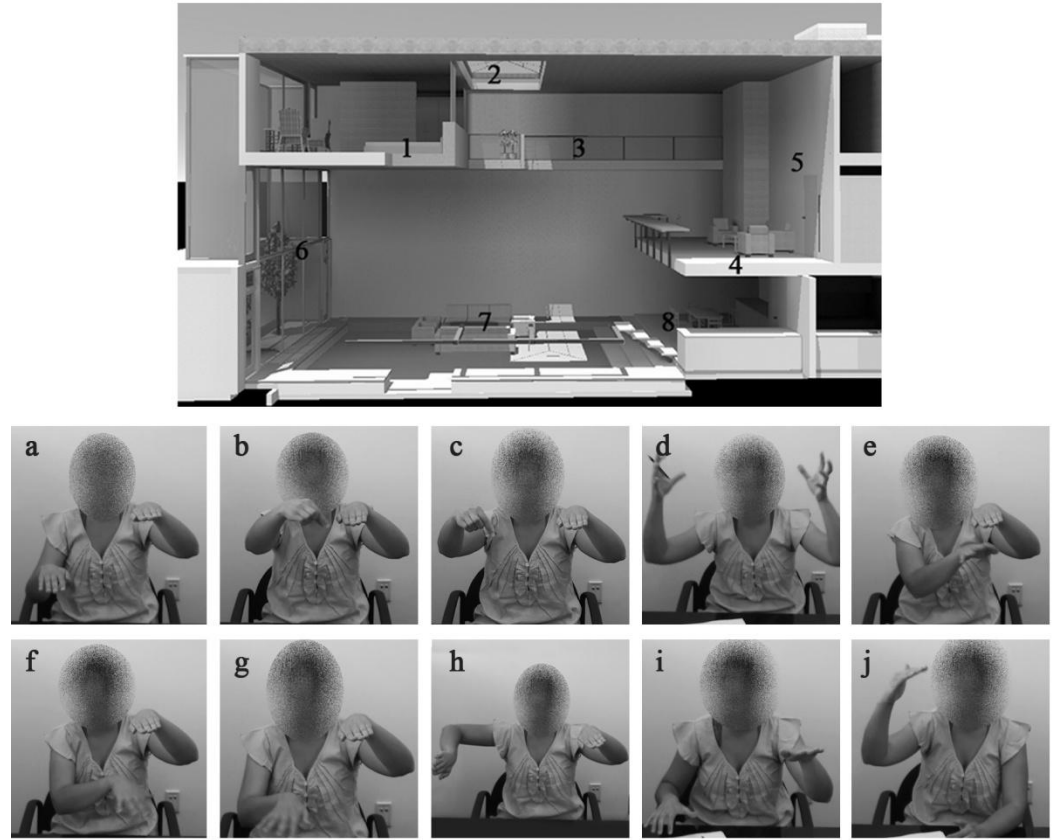


Figure 21 Participant's rendering the 3D SS model of the building by depicting different portions of the building without any specific order. Here the participant is facing the model from south as depicted at the above portion of the Figure. In **a** the participant was showing the relative locations of **1** -guestroom slab and **4** -the balcony slab; in a continuous movement from **b** to **c** she was depicting **3** -the bridge; in **d** she was showing how big is this void space; from **e** to **f** she was defining **6** -the area under the guestrooms slab and its being bounded by a two floor height window; in **g** she was talking about **7** - the living room area, in **h** she was showing **5** -the bounding wall of the volume, in **i** she was showing **8** the location of the dining area below the balcony at **4**, in **j** she was describing **2** -the skylight above the roof.

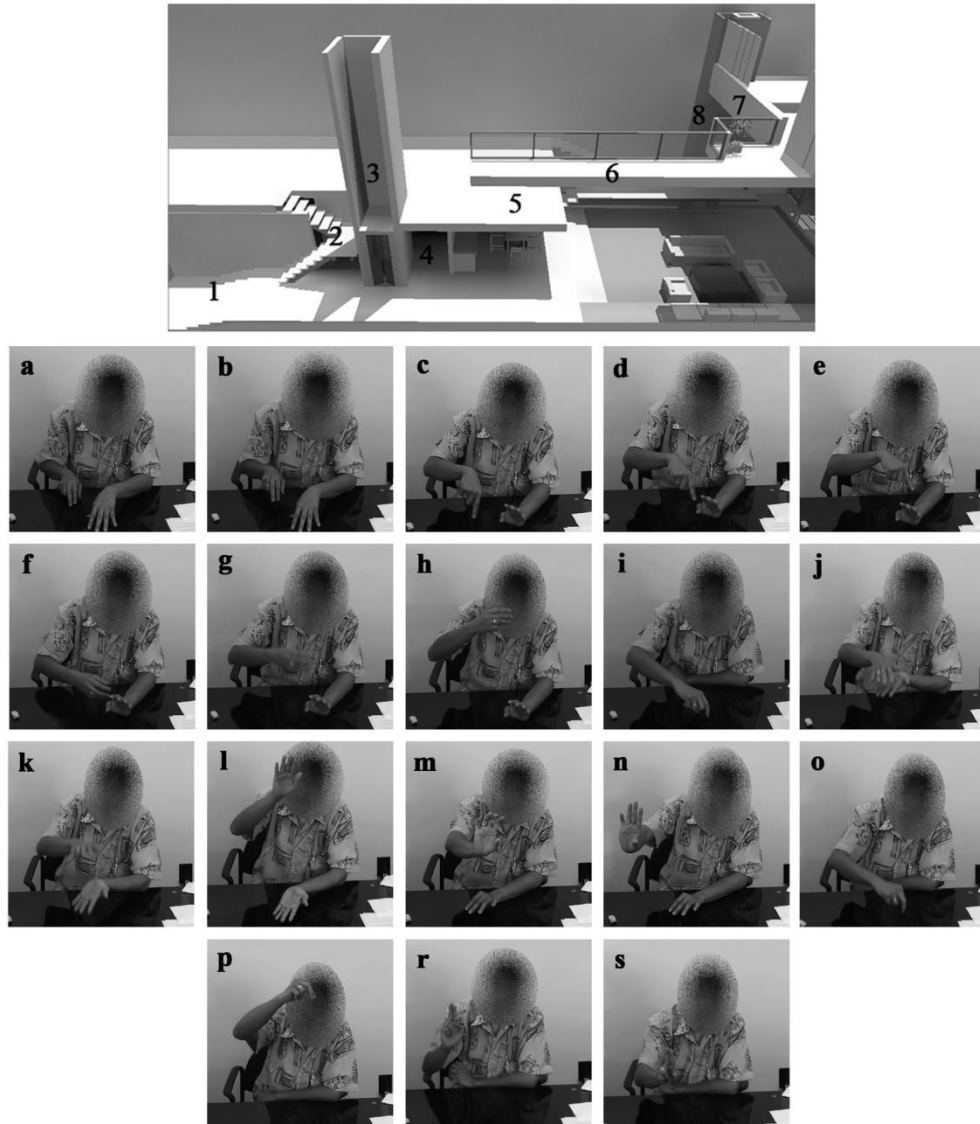


Figure 22 Participant's rendering a 3D SS model of the building by depicting the spaces in the order they would be encountered on a path starting from the entrance. Here through sequences of gestures he produced from **a** to **b** the participant was describing climbing the steps of the stairs at **1**; the snapshots **c**, **d**, and **e** are from his continuous movement of his hand when he was depicting the U shape of the stair at **2** climbing to the above floor. The snapshots from **f** to **h** are from his sweeping the elevator located just after the stairs from the current floor to the roof level. In **i** he was depicting the recession in front of the room opening to the area at **4**. In **j** he depicted the height of the balcony area in the gallery space and then from there, he opened up his hands to show the overall height of the space. Continuously from **m** to **n** he was depicting **7** -the balustrade like bounding wall of the guestroom space. From **o** to **p** he was continuously raising his hand up to the roof level to indicate **8** -the rising chimney of the fireplace. From **r** to **s** he was showing **6** -the bridge that connects the guestroom to the front side of the house.

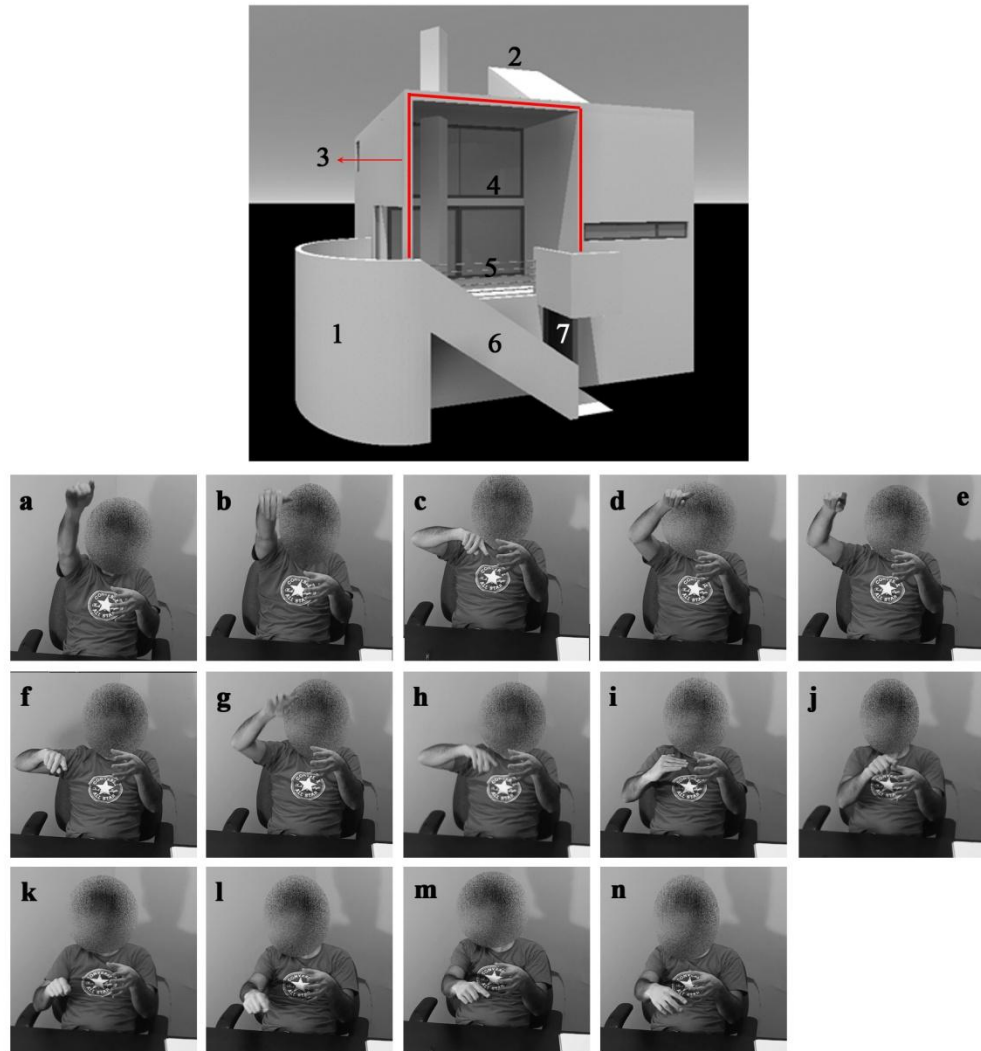


Figure 23 Participant's rendering of a 3D SS model of the B2 from its southwest corner. Here during his description, the participant was continuously depicting **1** -the half cylindrical form of the study room with his left hand. **a** and **b** are taken when he was describing **2** – the triangular mass at the other corner of the building. Snapshots from **c** to **f** are taken when he was depicting **3** -the shape of the void on the south side of the building. From **g** to **h** he was depicting **4** -the void space inside **3**. In **i** he was showing **5** - the deck area. From **j** to **k** he was moving his hand continuously to depict **6** -the stair case connecting the deck area to the ground floor. From **l** to **m** he was showing **7**, the entry way and entering to the open area at the North West corner of the ground floor and during **n** he was continuously moving his hand with circular motions while describing the open area and that it is behind this corner of the study room.

Form 3- Visualizing the Building in 3D in LS by Situating Self within the Building Environment

Some participants, while describing their visualizations of B1's interior space(s) or the outside form of B2 depicted the relative locations and the appearance of the components as if they were imagining being actually situated within the building environment, inside B1 or outside B2. Since in these occurrences, the participants seem to be imagining the buildings almost in actual size, I call these occurrences 3D LS (LS) visualization. Figure 24 presents some snapshots from a participants' 3D LS visualization of the gallery space of B1 when positioned at location 1. Figure 25 presents some snapshots from a participant's 3D LS visualization of southwest corner of B2 when positioned at location 1, 30 feet, or around 9 meters, away from the building.

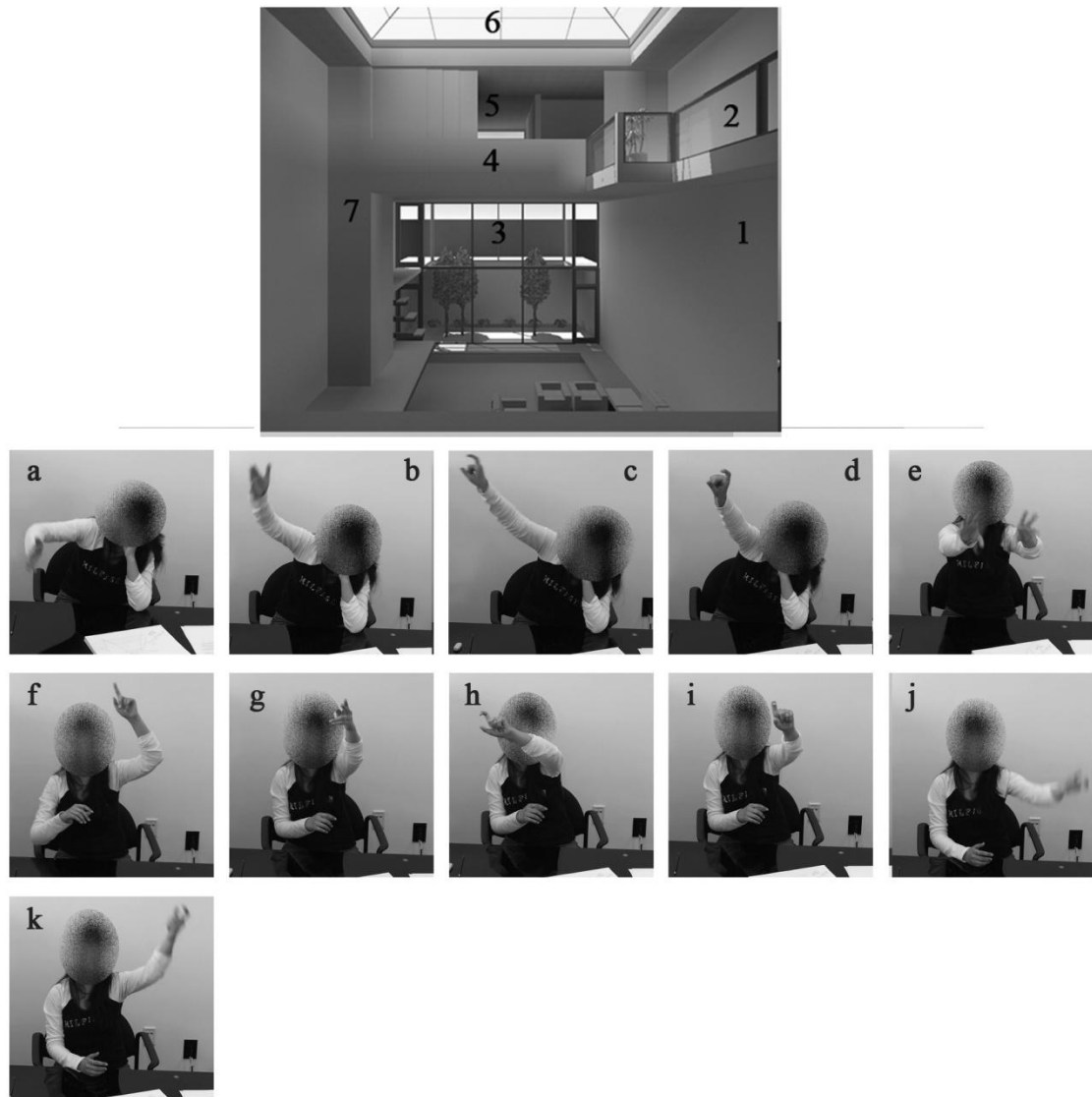


Figure 24 Participant's 3D LS visualization of the gallery space of B1 from location 1. Here from **a** to **b** the participant was depicting **1** -the bounding wall of the gallery space on her right. From **c** to **d** she was depicting **2** -the bridge going to the guestroom. In **e**, she was describing **3** that she can see a frame of the outside from the glazing below the guestroom block. In **f**, she was showing **6** -the skylight- and in **g** she was showing **5** that she would see inside the guestroom when the sliding walls are open. Continuing from **i** to **j** she was showing **7** -the rising wall of the fire place to the roof.

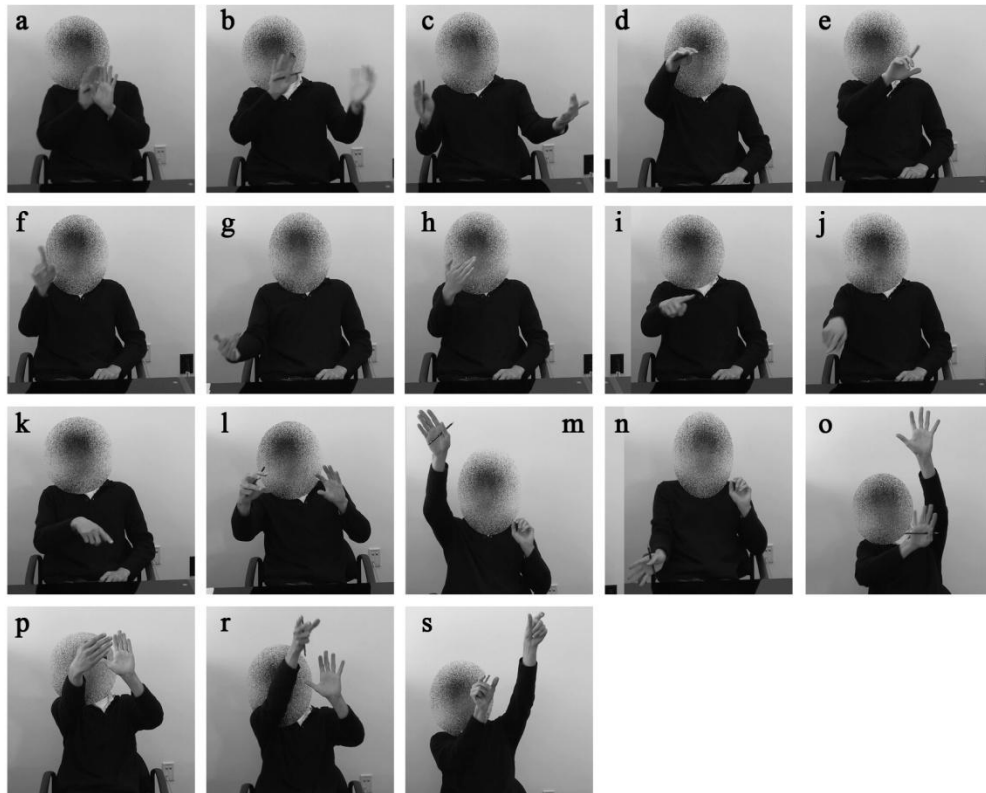
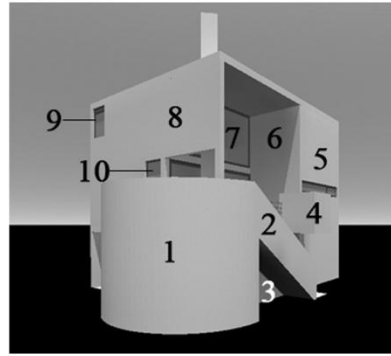


Figure 25 Participant's 3D LS visualization of the southwest corner of B2 when 30 feet away from the building. Here from **a** to **c** the participant was depicting the curvilinear form of **1** that protrudes toward him. In **d** he defined the relative height of **1** and from **e** to **f** he defined that **1** also rises to the terrace and bounds the terrace area as a railing. From **g** to **h** he depicted the rise of **2** from **i** to **j** to **k** he drew **3** -the triangular recession under the stair. In **l** he depicted **4** -the small balcony. From **m** to **n** he depicted **5** -the wall of the mass at the southeast corner of the building. In **o** he was depicting the arrangement of **8** and **1** and was describing that **8**-part of the west wall -only comes out on the highest floor level and so that there is an opening defined between **1** and **8**. In **p** he was depicting **8** and **6** at two sides of the void and in **r** he was depicting **7**, the double height glazing at the back of this void. In **s** he was showing the relative positioning of **9** and **10** -the two windows at the west façade.

Intermittent Occurrences of Component Defining

In addition to the three major forms of visualization, one aspect observed in most of these participants' visualization processes was the intermittent occurrences of single units of gestures that took place during these participants' rendering a 3D SS or LS model of the building in their gesture spaces. In these occurrences of single units of gestures, which I will here after refer to as intermittent occurrences of component defining, the participants all of a sudden depicted a form attribute -2D or 3D shape, height or width- of a component, which they already located in their 3D SS or LS gesture models of the visualized building space or form, outside its spatial context and mostly in a scale independent from that of the rendered 3D SS or LS gesture model. For instance, one participant, after locating a railing in a 3D SS model, depicted the height of railing in its actual size at the immediate front. In another instance, a large triangular mass on the roof of the building after it was located in a 3D LS model, was depicted as a as a small 3D triangle out of the model.

In the examination of these participants' visualization protocols in each of the five visualization tasks, it was seen some participants switched between different forms of visualization during their visualization of a building space/form in each one or more of the visualization tasks. Table 13 summarizes the forms of visualization and the occurrences of the intermittent episodes of the component defining (referred to as Int. CD) observed in each of the participant's visualization protocols in each of the five tasks; it in total reports about observations made in 11 participants' visualization protocols since two of the participants' visualization protocols did not qualify for an in-depth examination of the gestures as they were non gesturing participants.

In Table 13, each form of visualization has been reported along with the terms 'dominant' (Dom.) and 'intermittent' (Int.). Here the term 'dominant' is used to underline the considerable extent of the portion of the building space/form that was visualized in that reported form of visualization. The term 'intermittent' is used to refer to the form of

visualization which the participant, while visualizing most portions of the building space/form or the various spaces/form of the building in the walking tasks in the reported dominant form, switched to for a brief episode¹¹, for visualizing a small portion of the described building space/form or the building layout/form in the walking tasks. Thus, it should be noted that the ‘dominant’ and ‘intermittent’ forms of visualization refer to the form of visualization in which the participants’ imagined a large and small portion of the described building space(s)/form respectively not the amount of gestures produced to render the described building space/form in that form. For instance one participant in task #1-B1-W during her walkthrough had been visualizing the surrounding in the various spaces in 3D LS. While she was visualizing the gallery space at the time from a location at the living room area, she all of a sudden switched to 3D small scale visualization and described the connection of the side platforms and the stair in that space by visualizing them in 3D SS, then she resumed her dominant form of visualization and continued to describe that space and the subsequent spaces on her path in 3D LS. After a while, she then switched to 2D SS visualization, much like taking a glance at the 2D arrangement of the building spaces at one portion of the building, and then again returned to her dominant form of visualization.

¹¹This is a general case, yet there were exceptions where the participant took her time to think about that portion which lead to a longer duration in a sense the term can be understood metaphorically which in some cases basically means that it was the visualized portion being a relatively small portion of the building in comparison to the portion visualized in LS

Table 13 Forms of visualization observed in participants' visualization protocols within the various visualization tasks in this study

Par#	Task #1-B1-W	Task #2-B1-S	Task #3-B1-S	Task #1-B2-S	Task #2-B2-W
A1	Dom. 3D SS Int. CD	Dom. 3D SS	Dom. 3D SS Int. 3D LS Int. CD	Dom. 3D SS Int. CD	Dom. 3D SS Int. CD
A2	Dom. 3D LS Int. 2D SS Int. 3D SS	Dom. 3D LS Int. 3D SS	Dom. 3D LS	Dom. 3D LS	Dom. 3D LS
A3	Dom. 3D SS	Dom. 3D SS	Dom. 3D SS	Dom. 3D SS Int. CD	Dom. 3D SS
A4	Dom. 3D LS Int. 2D SS	Dom. 3D LS	Dom. 3D LS Int. 3D SS Int. CD	Dom. 3D LS Int. 3D SS	Dom. 3D LS Int. 2D SS Int. CD
A5	minimal gesture	minimal gesture	minimal gesture	minimal gesture	minimal gesture
A6	Dom. 3D LS Int. 2D SS Int. 3D SS	Dom. 3D LS Int. 3D SS Int. CD	Dom. 3D LS Int. CD	Dom. 3D LS Int. 3D SS	Dom. 3D LS Int. 2D SS Int. 3D SS Int. CD
A7	Dom. 3D SS	Dom. 3D SS	Dom. 3D SS Int. 3D LS	Dom. 3D SS	Dom. 3D SS
A8	Dom. 3D LS Int. 2D SS Int. 3D SS	Dom. 3D LS Int. 3D SS	Dom. 3D LS Int. 3D SS Int. CD	Dom. 3D LS Int. 3D SS	Dom. 3D LS Int. 3D SS
A9	Dom. 3D LS Int. 2D SS	Dom. 3D LS Int. 3D SS Int. CD	Dom. 3D LS	Dom. 3D LS Int. CD	Dom. 3D LS Int. CD
A10	Dom. 3D LS Int. 2D SS Int. 3D SS	Dom. 3D LS Int. 3D SS Int. CD	Dom. 3D LS	Dom. 3D LS Int. 3D SS	Dom. 3D LS Int. 2D SS Int. CD
A11	Dom. 3D SS	Dom. 3D SS	Dom. 3D SS Int. 3D LS	Dom. 3D SS	Dom. 3D SS
A12	Dom. 3D SS Int. CD	Dom. 3D SS	Dom. 3D SS Int. CD	Dom. 3D SS Int. CD	Dom. 3D SS
A13	minimal gesture	minimal gesture	minimal gesture	No gesture	No gesture

In the analysis of the participants' visualization protocols, two major patterns were discerned among these participants with regard to the form of visualization that was dominantly employed by each participant in all the visualization tasks. It was seen that six of these participants in all visualization tasks had substantially visualized the building spaces and forms in 3D LS whereas five of these participants, in all visualization tasks, had substantially visualized the building spaces and forms in 3D SS. For the purposes of differentiation, from here after, these six participants will be referred as large-scale-visualizing (LSV) participants and these five participants will be referred as small-scale-visualizing (SSV) participants.

As could be seen in Table 13, in most of these architects' visualizations, there were also short episodes of other forms of visualization and intermittent occurrences of component defining. The following section provides a brief synopsis of the observations made in these architects' mental visualization processes in each of the five visualization tasks. It first discusses the patterns of visualization observed in the LSV architects' visualization processes. Then it discusses the patterns of visualization observed in the SSV architects' visualization processes.

5.1.2 Forms of Visualizations within Tasks

LSV participants' Visualizations of the Building's Space(s)/Form within Tasks

The participants were asked to carry out mainly two types of visualization tasks. The first type comprised the standing tasks, tasks # 2-B1-S, # 3-B1-S and #1-B2-S, where the architects were asked to visualize the buildings spaces/form by imagining themselves standing at the given locations; this was what the LSV architects mainly did in these tasks except for the brief episodes where they switched to 3D SS visualization for imagining the 3D arrangement of some of the components in the visualized building space/form space. The second type comprised the walking tasks, tasks #1-B1-W and #2-B2-W,

where the participants were asked to visualize the building's interior/exterior space(s)/form by imagining themselves walking inside/around the building. These two tasks were mainly calling for concurrent imagination of the action of walking and the sequences of views to be encountered while walking; yet, these participants did not do so. In these tasks, the LSV participants' mainly described and depicted the appearance of the various spaces that they encountered on their paths in B1 and the different views of the B2's exterior form to be captured along their paths around B2 as if they were standing still inside each space or at different areas of the same space of B1 and at different directions outside B2 rather than walking. Furthermore it generally took these participants only a few seconds to reach at the subsequent areas or spaces in B1 and different sides of B2 at varying distances as if they were imagining jumping or teleporting from one area/side of the building to another rather than walking. In most cases, the time these participants took to imagine walking varying distances was equal to the time it took them to mention about their relocations by phrases that indicate relocation or movement. For instance, in B1, one participant, after mentioning that she is in front of the kitchen area at the ground floor (which is near to the stairs to the first floor balcony area) climbed the stairs and reach to the first floor area in the few seconds that took her to mention that "if I go up from that stair, secondary (she means the secondary stairs of the house)" and continued to describe the balcony area as "I find like a sliding door...". Another participant climbed up the stairs from the first to the second floor in the few seconds that took her to mention that "so you take up that staircase and you are at level three now". Likewise, in B2, a participant went from West side of the building to its North West, which is around 10 meters away on the path, in the time it took him to say that "if I continue to walk around the building in clockwise". It took another participant to go from northeast side to east the time to mention that "continuing towards the eastside of the building".

A similar jumping like relocation was also observed when these participants in B1 were asked to walk back from the last location they reached in their imaginations of walking (which was mostly the second floor guestroom) to the balcony area at the first floor of B1. The question was directed as ‘can you now from ‘the current location’ walk me back to the balcony area? Interestingly, none of these LSV participants, in response to this question, started to visualize and describe what they would be seeing if they were to be walking back to the balcony area. Rather some participants took a few seconds of pause and said ‘yes’ implying that they are already at the balcony area and waiting for my next question and some others directly mentioned that they are at the balcony area as if they all teleported themselves to the balcony area.

All of the LSV architects, in the walking tasks #1-B1-W and #2-B2-W, had one or more intermittent episodes of 2D SS visualization where they visualized the 2D layout of a space or building on site, or a portion of the floor layout in SS. Furthermore, all these architects, in one or more of all the five tasks, had intermittent episodes of 3D SS visualization where they imagined the arrangement of some of the components in the visualized building space/form in SS. In the examination of these intermittent episodes of other forms of visualizations, some interesting patterns were found with regard to the circumstances under which they took place.

As summarized in Table 14, all the intermittent episodes of 2D SS visualization that occurred in the walking tasks, took place under the same circumstance. This common circumstance, as I will discuss below, led to the interpretation that these architects mainly switched to 2D SS visualization because it helped them to keep track of the spaces/components of B1/B2 to be encountered on their path and their relative positions on the floor/site layout of B1/B2 or inside the gallery space of B1. The intermittent episode(s) of 3D SS visualization took place in these LSV participants’ visualization processes in one or more of the five visualization tasks had taken place under one of the three common circumstances; as I interpreted and will discuss further, these architects

mainly switched to 3D SS visualization at the times (1) when there was the possibility that some of the components inside/at the visualized space/portion of the building would not be seen from their current locations due to their visibilities likely being blocked by the closer components (2) when the participants were not clear about the 3D layout of some of the components inside/at the visualized building space/form and (3) when they wanted to recap the connections between multiple components and their spatial relations with each other and the containing space/form. Table 14 summarizes the percentage of the LSV participants who switched to 3D SS visualization during their LS visualization processes under each of these different circumstances and across all tasks. In this table, these circumstances are shortly referred as (1) possible non-visibility of components, (2) unclear about the 3D layout of the components and (3) recapping the 3D arrangement and connections of multiple components. The rest of this section gives a brief synopsis of each of these common circumstances as observed in these participants' visualization processes in the different tasks.

Table 14 Percentage of LSV participants who switched to 2D and 3D SS visualization in their visualization processes

Task #	#1- B1-W	#2- B1-S	#3- B1-S	#1- B2-S	#2-B2- W	Across all tasks
% of LSV participants who switched to 2D SS to keep track of relative position/upcoming space/components	%100	%0	%0	%0	%50	%100
% of LSV participants who switched to 3D SS visualization	%66	%83	%33	%66	%33	%100
- <i>possible non-visibility of components</i>	%33	%83	%0	%33	%33	%83
- <i>not clear about the 3D layout of components</i>	%33	%0	%33	%33	%0	%50
- <i>recapping 3D arrangement and connections among multiple components</i>	%33	%0	%0	%16	%0	%50

LSV Participants' Switching to 2D SS Visualization as a Means for Keeping Track of Their Relative Positions on Building's Floor/Site Layout

In %100 (6 out of 6) of the LSV participants' visualization processes in task # 1-B1-W, intermittent episode(s) of 2D SS layout visualization were observed to take place at the times they were about to change or in the process of changing their relative positions on the building's floor/site layout. For instance, while the participant is imagining oneself inside the corridor space at the second floor of B1, from where she could pass to a number of alternative spaces, she was beginning to go back and forth between 2D SS visualization of that portion of the layout and 3D LS visualization and passing on to describe a subsequent space in 3D LS. Another participant, while relocating from one location to another in the gallery space, was pointing to the table surface as if an invisible 2D layout of floor is lying in front of him and he was pointing the location he was about to describe on that invisible layout. Among these architects' intermittent switches to 2D visualization, two different forms were observed with regard to how they referred or depicted the 2D SS layout in their gesture spaces when imagining themselves at different portions of the layout. The first form was observed when the participants were imagining themselves at the enclosed spaces at the front side of the house. In this form, the participants mainly rendered the 2D layout of a number of adjacent rooms at the front side of the floor level sometimes by drawing invisible lines and sometimes pointing to invisible locations on the table surface or on an invisible horizontal plane above the table surface. In most participants' visualization processes, these intermittent episodes of 2D SS visualization took place in an interrupted fashion in that they were going back and forth between LS visualization of a space and visualization of the 2D layout of the nearby spaces. The second form was observed when the participants were referring to be looking at the different areas and levels inside the gallery space. In this form, the participants mainly pointed to invisible locations on the table surface rather than rendering the

boundary and the layout of the space as they did when they were at the enclosed spaces at the front sides of the floors. In most of these participants' visualizations of the gallery space, these occurrences were not very frequent to match the relative positions of the pointed locations to each other. Yet it was possible to examine these pointed locations in relation to the relative locations of the enclosed spaces depicted on the table surface. In these examinations it was seen that the invisible locations closely correspond to the referred to locations inside the gallery space at that time of the speech.

The second form of 2D SS visualization was also observed to take place in %50 (3 out of 6) of the participants' visualizations of walking around B2 in task #2-B2-W. In these intermittent episodes of 2D SS, the participants, at the times they mentioned their new relative positions at the building's site, mainly pointed to invisible locations on the table surface. In the examination of the series of invisible locations that they pointed to on the table surface, it was seen that these invisible locations was corresponding to the locations that these participants would point to if a 2D plan of the building were to be in front of them with the same orientation and with a scale around 4-5 times larger than that of the presented plans.

In total % 100 (6 out of 6) of participants were observed to switch to 2D SS in one or both of the two walking visualization tasks, tasks #1-B1-W and #2-B2-W. What these participants appeared to be doing in these intermittent episodes of 2D SS visualization resembled an action that I and I suppose many people do when playing a video game in a virtual environment: taking quick looks at the 2D map of the environment while navigating through its various spaces or areas. I propose that these participants had quick imaginations of the 2D layout of the floors or the gallery space of B1 and the site layout of B2 in their visualization processes because this was providing the participants an overall view of these layouts. By providing an overall view, these 2D SS visualizations were helping them to keep track of their relative positions in the floor/site/room. These visualizations were also helping them to keeping track of the relative spatial locations of

the nearby spaces that they would proceed to on their paths in B1 and possibly the relative spatial locations of the various masses of B2 that they would be facing at from different directions in their paths around B2.

The floor levels at the front side of B1 have a more fragmented organization when compared to its main gallery space. At the front side of B1 each floor level houses multiple enclosed spaces in which one would not have a visual access to the adjacent spaces. Some of these enclosed spaces can be accessed through different paths which provide multiple navigation options. On the other hand gallery space is a multilevel open space with open areas at different levels. At each of these levels one can apprehend most of the surroundings and it is much easier for one to keep track of her relative position in this space. Likewise, keeping track of one's relative location on the building site is much easier than keeping track of oneself inside the building at an area which has multiple spaces with multiple navigation options.

Because the floor layouts at the front side of B1 have a more fragmented organization than its gallery space, it was more difficult for these participants to keep track of their relative positions and the spaces to be encountered on their path at this side of the B1 than the cases where they imagined themselves relocating inside the gallery space of B1 or outside B2. This was why the short episodes of 2D SS visualization were observed more frequently in these participants' imaginations of the enclosed spaces at the front side of the house and mainly in the form of renderings of the layout of the nearby spaces. This was also why participants less often indicated their relative locations in the gallery space and why, both in the gallery space of B1 and outside B2, they indicated their locations in a much simpler form by just pointing these locations on the invisible space/site layout rather than rendering a more detailed layout on the table surface.

As can be seen in Table5.2, such intermittent episodes of 2D visualization were not observed in the tasks where architects were requested to imagine themselves at a given location and visualize their surroundings. This make perfect sense when looked

from the perspective that in these cases they did not need to keep track of and update their relative locations on the buildings' floor or site layout. Thus it further supported the view that these participants' switched to 2D SS visualization as a means for keeping track of their relative positions in the building's spatial layouts.

LSV Participants' Switching to 3D SS Visualization When They Were Not Clear about the Visibility of the Components

Among the LSV participants, %33 (2 out of 6) in their visualization processes of walking in task #1-B1-W and %83 (5 out of 6) in their visualization processes of gallery space of B1 in #2-B1-S, were observed to switch to 3D SS visualization when they were visualizing the gallery space from the upper level(s) (the balcony area at the first floor and the bridge at the second floor level). In these intermittent episodes, these participants, just after they imagined most portions of the gallery space in 3D LS, switched to 3D SS visualization as they began to describe some of the components that they were seeing at below portion of the gallery space.

If one were to look towards the gallery space from the balcony area, the view of the level below would partially be blocked by the slab and/or the desk like balustrade of the balcony to some extent depending on how far she is from the edge of the balcony. For instance, if one stood far from the edge, as depicted in Figure 26b, one would not see most of the living room area; most of the components at the living room area would be partially blocked by the top cover of the balustrade and its posts but one would have a glimpse of the stairs connecting to the balcony area. If one stood close to the edge, as depicted in Figure 26a, which was the case in their visualizations of the gallery space from location 1 in task #2-B1-S, one would see the components at the far end of the living room wholly, and the some portion of the sides of the U shaped platform surrounding the living room, and some portion of the platform on the left. In both cases, one would not be able to see the fireplace itself, but only its surrounding wall rising

above the platform on left. In these participants visualizations of the gallery space from location 1 in task 2-B1-S, the components at below that they visualized in 3D SS were mostly the components which would very likely be partially or not visible from this location. In these instances, these participants were mainly depicting the 3D layout, shapes and dimensions of these components wholly, as would be in a 3D SS model of the level below, regardless of the fact that some of these components would only be partially visible or not visible from the given location. In the meanwhile they were verbally expressing that they were, they should or they think they would be seeing some of these components partially.

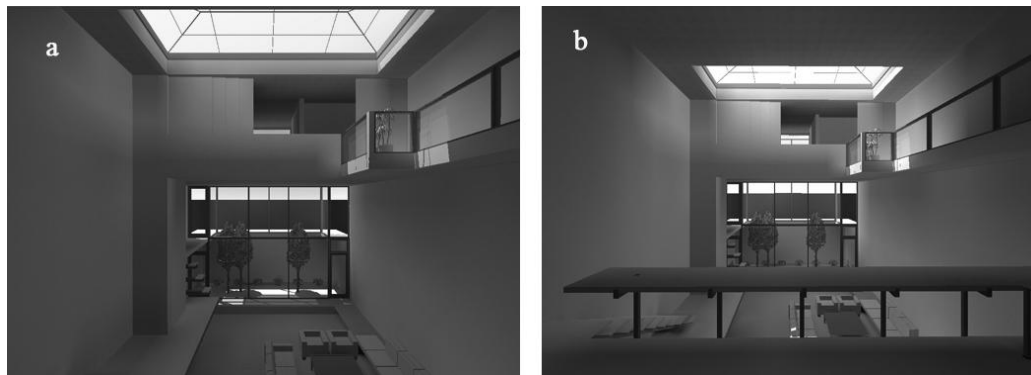


Figure 26 Appearance of components at the level below the balcony area when looked from different distances from the edge of the balcony area

Later % 33 (2 out of 6) of these LSV participants in their visualization processes of B2 in task #1-B2-S and walking around B2 in task #2-B2-S were observed to switch to 3D SS visualization when they were imagining two of the components, the triangular and cylindrical masses, which were at the far end of the roof at their current relative locations outside the building. One thing common about these occurrences was that, while they were gesturing the forms and arrangement of these components in the way they would be in a rough 3D SS mass model of the building, the participants were saying that they should be seeing one or both of the components partially from the given location. Indeed,

one thing common about these two components was that these components would very likely be partially or not seen from the locations that these participants at that moment were imagining themselves at. These locations were 9 meters away from the building and were at its southwest, south and south east sides. As depicted in Figure 27, at each of these sides of the building, which one or ones of these components a person would see mainly depends how far the person is from the building or the height of the viewpoint. As can be seen in this figure, none of these components would be seen if one were to look at this building from the given location.

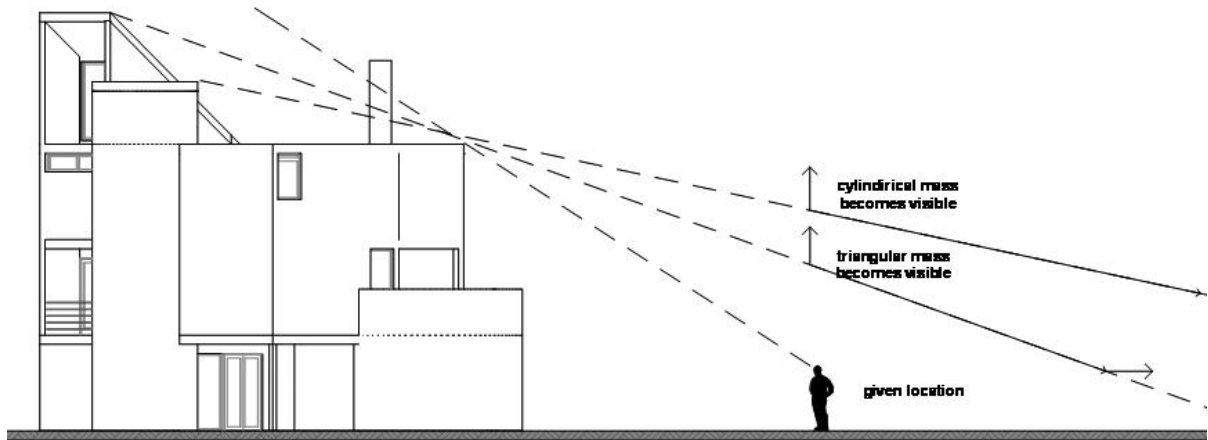


Figure 27 Non visible components when looked at from the given location and the distances and heights from which they would be visible

Observing the circumstances under which %83 (5 out of 6) of the LSV participants switched to 3D SS visualization in their visualization processes in one or more of the visualization tasks, I propose that it was difficult or maybe impossible for them to visualize a building space/form from a particular location, or specific viewpoint in their imaginations. Therefore, in their visualization processes of the gallery space of B1 in task #2-B1-S, it was difficult or maybe impossible for these participants to define which of the components at the level below would be partially or not visible from the

given location. In the same respect, it was difficult or maybe impossible for them to define whether they would see the triangular and cylindrical masses from their respective locations outside B2 in the tasks #1-B2-S and 2-B2-W.

In their visualizations of the gallery space of B1, these LSV participants knew that they would very likely partially see or not see some of the components at the level below because the balcony slab and/or balustrade would block their view to a certain extent. Yet, since they could not imagine and depict the appearance of these components in the way they would appear from the given location, they visualized and depicted the arrangement of these components in 3D SS; and in the meanwhile verbally expressed that they were, they should, or they think they would be seeing some of these components partially. This was also the case observed in %33 (2 out of six) of these participants' intermittent 3D SS visualizations of the below portions of gallery space from the balcony and bridge areas in their visualizations of walking in B1 in task # 1-B1-W. In these occurrences, at which locations these participants imagined themselves at the balcony or bridge area was not exactly known since the participants selected their own paths and locations in this task. Yet, wherever they imagined themselves at the balcony or bridge area, there was the possibility that their view of some portions of the levels below would be partially blocked by the slab or balustrade of the balcony or of the bridge. Accordingly, some of the components at the below level(s) would very likely be partially or not visible from their respective locations.

Similarly, in the cases where % 33 (2 out of 6) of these LSV participants' switched to 3D SS in their visualization processes of B2 in the tasks #1-B2-S and #2-B2-W, these participants knew that they might or might not see the cylindrical block and the triangular mass from their respective locations or might see one or both only partially as they were at the far end of the roof with respect to their relative locations on the site at that moment. Yet, since they could not imagine and thereby externally depict the appearance of these components in the way they would appear from the given location,

they visualized and depicted their 3D arrangement within the context of the building mass in 3D SS while mentioning that they think, they should be or not be seeing one or both of these components.

While these participants switched to 3D SS visualization at the time they were about to describe these two components of B2 in task #1-B2-S, it was seen that %50 (3 of 6) of the LSV participants, who continued to visualize these components 3D LS, identified one or both of these non visible components as partially visible from the given location. This further indicates that these participants most likely did not capture the appearance of this building in their LS imaginations in the way it would be captured when looked from a specific location and thereby provided further support to my view that they did not capture because it was difficult or maybe impossible to do so.

LSV Participants' Switching to 3D SS Visualization for Figuring out the 3D Arrangement of the Components That They Were Not Clear about

In their visualization processes of walking in task #1-B1-W, %33 (2 of 6) of these participants as they came to the point of describing what they see when looking towards the greenhouse through the windows of the gallery area, started talking about not being clear about or not recalling the exact arrangement of the greenhouse portion of the house. At this time, they started visualizing and modeling the arrangement of the components in the greenhouse space in 3D SS. As soon as they finished imagining the arrangement in greenhouse in 3D SS, they resumed their most recent locations in the gallery space and went back to imagining how the greenhouse would appear in 3D LS when looking at it from that location.

In their visualization processes of the gallery space in task #3-B1-3, % 33 (2 of 6) of these LSV participants, after talking about not exactly recalling how the walls at the east side of the gallery space were arranged, started to model their arrangement in 3D SS.

After doing so, they returned back to visualizing the space in 3D LS and they re-depicted the appearance of these walls from their current location in 3D LS.

In his visualization processes of B2 from location 1 in task #1-B2-S, one of these LSV participant developed a 3D SS model of the arrangement of the interior spaces at the east side of the building. In the meantime he was talking about not being clear about this portion of the building and how much that block protruded out towards the south and what would be the arrangement of their respective windows on the façade. In the same task, another LSV participant, after visualizing the appearance of the southwest portion of the building in 3D LS for a while, started to visualize and re-model the east block and the recessed south façade relation in 3D SS as she was talking about not being clear about how much the wall was recessed on the terrace and how the components there are arranged relatively.

In all the above occurrences, in total %50 (3 of 6) of the LSV participants in their visualization processes in one or more of the tasks, were observed to turn to 3D SS visualization for visualizing the 3D arrangement of components that were not clear to them instead of trying to directly visualize them in their dominant form of visualization. Furthermore, all these participants, in one or more tasks, right after they returned to their dominant form of visualization were observed to re-visualize the appearance of these components in 3D LS. My interpretation is that these participants did so basically for one or both of the two main reasons. First, 3D SS visualization of a building composition, as would be in the case of inspecting a 3D SS physical model of the building, was a more effective form of visualization than 3D LS for apprehending the overall spatial configuration of the components in various parts of the building space/form at once and thereby for figuring out their arrangement. Second, visualizing in 3D SS in general was cognitively more affordable, i.e. putting lesser demands on the cognitive processes and capacities, for the participants than imagining how that space or composition would appear if they were to look at it from an inside perspective. Accordingly, it was a more

convenient form of visualization to imagine and figure out the 3D arrangement of the components that they were not clear about. My proposal is that these participants had visualized those unclear portions of the building in 3D SS both because (1) it was a more effective form of visualization for figuring out the 3D arrangement of components and (2) because it was cognitively more affordable to do so than imagining their appearance in 3D LS.

LSV Participants' Switching to 3D SS Visualization for Recapping the 3D Arrangement and Connections among Multiple Components

A common situation observed in the intermittent episodes of 3D SS visualization in %50 (3 of 6) of the LSV participants' visualization processes, was these participants' imagining and modeling by gesturing the spatial arrangement of some of the components in the building space/form in 3D SS after having had visualized and rendered these components in 3D LS. For instance, one participant during her visualization process of the gallery space of B1 in 3D LS, all of a sudden, just after she visualized and depicted the relative locations and shapes of the side platforms and the connecting stairs, switched to 3D SS for a brief episode; in this episode, she visualized and described how these side platforms and the connecting stairs were related to each other and modeled their arrangement in 3D SS. Likewise one participant during his visualization of the same gallery space in 3D LS, just after he located and depicted the guestroom block in his 3D LS model of the space, switched to 3D SS visualization for a moment and started modeling the relationship of the guestroom block with the gallery space and described to what extent it protrudes into the space.

In these occurrences, it seemed like these participants recapped how these components are connected to each other and related to space/form through 3D SS visualization. They did so in 3D SS because this form of visualization provided them the opportunity to capture and model the connections between multiple components at once

much like having an overall view of them in a 3D small scale model of the building rather than apprehending them in the real building through multiple frames of views.

Based on the above observations, the understanding I attained with regard to the features of these architects' LS visualizations was as follows:

- These LSV architects when visualizing the building space(s)/form by imagining themselves standing at the given locations, visualized the building space(s)/forms in 3D in (almost) its actual size. Yet, what these participants experienced in these tasks were not a continuous visualization experience of the building space/form from within; rather they were alternating experiences blended with intermittent episodes of 3D SS visualization.
- These LSV participants', while carrying out the walking tasks, did not imagine themselves walking; rather they imagined themselves much like jumping or teleporting from one location to another on a path which has a series of stopping locations on it, and visualized the buildings' spaces or form in a motionless manner from each of these locations.
- What they experienced in their imagination, in the walking tasks, were not like the sequences of changing views to be encountered if one were to be really walking inside/around a building; rather they were much like a collage of sequences of 3D LS visualizations of different (parts of the) spaces or different sides of a building occasionally blended with 2D small scale visualizations of (certain portions) the building's floor or site layout , and 3D SS visualizations of the certain portions of the building space/form.

In the following, I will describe the patterns observed in SSV architects' visualization processes within the different visualization tasks and the understanding attained from them. Then, I will outline the overall inferences made about the nature of the mental representations that architects constructed during these LS and SS visualization processes in this analysis.

SSV Participants' Visualizations of the Building's Space(s)/Form within Tasks

In the tasks where the participants were required to visualize the building space/form by imagining themselves standing at the given location, tasks #2-B1-S, #3-B1-S, and #1-B2-S, the SSV architects mainly visualized and modeled the building space/forming 3D SS from the orientation of the given location as if building or inspecting an invisible half open SS model of that space from the given side or an invisible partial 3D SS model of the building's mass depicting the visualized portion of the building. Among these SSV participants, %40 (2 of 5) of them was observed to visualize the building space(s)/forms solely in 3D SS in all visualization tasks. As summarized in Table 15 Switching to another form of visualization was only observed in %60 (3 of 5) of these SSV architects visualizations of the building in one of the tasks; these SSV architects switched to 3D LS visualization for a short duration in their visualization processes of the gallery space of B1 in task #3-B1-S.

Table 15 percentage of SSV architects who switched to 3D SS visualization in their visualization processes

Task #	#1-B1-W	#2-B1-S	#3-B1-S	#1-B2-S	#2-B2-W	Across all tasks
% of SSV participants who switched to 3D LS visualization	%0	%0	%60	%0	%0	%60

There was an interesting commonality among these intermittent episodes of 3D LS visualization that took place during %60 (3 of 6) of these SSV architects visualization processes of the gallery space of B1 with regard to the portion of the space that was visualized in 3D LS. All these participants, after visualizing the arrangement of most of the components in the gallery space in 3D SS, switched to 3D LS visualization when imagining the appearance of the components, mainly the skylight and guestroom slab, that would be above them if they were to be situated at the given location. In these

intermittent episodes of LS visualization, these participants were talking about how much the guestroom slab would block their view of the skylight or whether they should be seeing the skylight from that location. Indeed, a critical aspect about these two components was the possibility that the guestroom slab would partially or totally block the visibility of the skylight when looked from the given location as depicted in Figure 28. My interpretation was that these participants did not want to define visibility of these components based on their 3D SS imaginations of the space because they knew that one of these components would very possibly block the visibility of the other to a certain extent when looked from the given location. Accordingly, they tried to visualize that portion of the space in 3D LS to capture whether or to what extent they would see the skylight behind the guestroom slab.

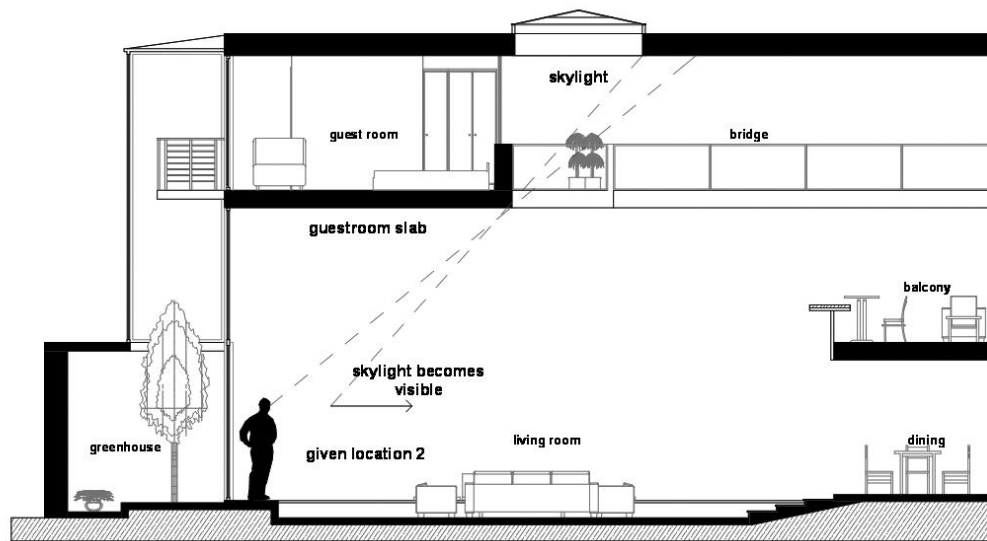


Figure 28 Guestroom blocking the visibility of the skylight when looked from the given location and until a certain distance inside the living room area

One other observation made here was that these SSV participants in their LS visualizations of the skylight and guestroom slab arrangement had reported the non-visible component -the skylight- as visible or partially visible from the given location.

Once this common situation was observed, LSV participants visualizations were examined to find out whether they did capture the guestroom's fully blocking the visibility of the skylight when they imagined the appearance this portion of the space from given location. It was seen %60 (3 of 5) of the LSV participants, who defined the guestroom slab in their LS visualizations of the gallery space, defined the non visible skylight as visible or partially visible from the given location. Thus, in overall among the participants who visualized the guestroom slab in 3D LS during their visualization processes, %75 (6 of 8) of them misidentified the skylight as visible or partially visible in their visualization processes. Based on these outcomes, my understanding here is similar to that of the LSV architects switching to SS visualization at the times when they were not clear about the visibility of the components; both these SSV architects in these intermittent episodes of LSV and the LSV participants during their visualizations of the gallery space predominantly in 3D LS including these two components, did not capture the appearance of this building as exactly as would be seen by the eye from this location. As previously, my proposal is that it was most likely difficult or maybe impossible to visualize a building space(s)/form in the way it would appear from a certain location.

In the mental walking task #1-B1-W, which originally required the participants to imagine themselves walking inside the various spaces of B1, the SSV participants in their visualization processes mainly rendered a SS model of the overall building in their gesture spaces by reaching it from a consistent side. %60 (3 of 5) of these participants rendered the 3D SS model of B1 by reaching it from the east side, where the entrance is. These participants in their visualization processes mainly described and modeled the 3D layout of the various spaces of the building and the components within in the order at which each space would be visited if they were to be following a walk path starting from the entrance. %40 (2 of 5) of these participants rendered the 3D SS model of the building by reaching it from its south side, in the same orientation that they looked at the building plans. These participants' in their visualization processes described and modeled the

various spaces of the building discretely without any specific order. These participants' continuously visualized the 3D SS models of the buildings in the same orientation throughout the visualization process was most likely a result of preferred orientation rather than an orientation specificity because all these SSV participants in the following visualization tasks in B1 had visualized the building model from the side of the given locations.

In their visualizations of B2 in task #2-B2-W, which originally required the participants to imagine themselves walking around B2 and imagine the appearance of the building from different directions, some differences were observed among the SSV participants' visualization processes with regard to the way they visualized the different side views of the building in 3D SS. In this study the participants were required to carry out the mental walking task #2-B2-W just after they visualized and drew their visualizations of B2 from the given location 1 which was at the southwest side of the building. In this task, they were asked to imagine themselves walking in the clockwise direction on a path 9 meters away the building which starts from L1. Most of these SSV participants' while carrying out this walking task, began to describe the appearance of B2 from West or North West as the first side view to be encountered after southwest.

One of these participants, as the first view, started to describe the appearance of the building from west. Just before he started his description, he held his hands positioned in the same orientation that he described the southwest corner of the building in the previous task; then leaned to his left as if the model he rendered from southwest were still staying in the same position and he was at the time trying to look at its west side. After depicting and describing the components at the west side of the building in this position, as he was about to proceed to describe the north west corner of the building, he made a rotational move with his hands as if he was now turning that invisible model up in the air to face it from the north west. After depicting and describing the northwest side, he then again leaned towards left to describe the north side of the building as if the model is still

standing at the same position. He described all the following views in a similar fashion, by leaning towards the left as if the model is staying at the same position and he was looking at it from a different direction or by rotating the model to face the side he was describing. It seemed like this participant was alternatively rotating a SS model of the building or inspecting it from different sides in his imagination for describing the appearance of the different sides or corners of the building.

Another participant first rendered and described the west side of the building as if he was facing the west side of the building at the time. As he was about to describe the succeeding side, the north side, of the building in the clock wise direction he positioned his one hand on one of the components on the west side at his front and his other hand on a component on the left on the north side. After he depicted and described the component at north side by locating it in this manner, he all of a sudden began to depict the same component in front of him as if he were now facing the north side of the model and continued to depict all the other components at his front. He did the same action in each of his transitions from describing one side/corner of the model to describing the succeeding corner/side at its left. It appeared to me that this participant was imagining the SS model of the building standing at the top of the table, and he was preparing to imagine the appearance of the other side of the model by referencing to a component at that other side of the model. Between this preparation moment and his starting to render the other side of the model at his front, he could be doing a number of things in his imagination. He could be imagining rotating the model to look at its other side or imagining to be looking at the model from a different side. examining this participant's protocol, I think he was mainly imagining himself looking at the model from a different direction and preparing to do so by taking a reference point on the new side of the building that he was about to imagine and then was imagining and depicting the new side of the model in his immediate front.

In the course of their visualizations of the building from different sides, the other three participants, mainly defined which side of the building they were about to describe mainly in words without producing any gestures such as “I will see in the back corner, the northern side” (A3) “What I see on the other side”, “Okay , I am on the side where you have the other like a circular stair like a smaller one” (A12) , or then as you go further, you’re almost in front of the circular stair and then as you go around, himm.. the main things you will be seeing” (A7). When describing each different side or corner of the building, they mainly rendered it directly in front of them as if they were facing that side or corner of a SS model of the building at the time. It was again possible that one or more of these participants were at the time imagining to be looking at the model from a different side or rotating the building model in their imaginations but not externalizing these spatial transformations in their gesture space. Examining these participants’ depictions of the different sides, I had the impression that the participants had been imagining themselves looking at the model from the different directions and were basically imagining and depicting the SS model of the building from in the way it would from each different direction in their immediate front.

Imagining rotating the SS model of the building and imagining oneself looking at the model from a different direction constitute examples of two classes of mental spatial transformations referred as *object-based spatial transformations* and *egocentric perspective transformations*, or “perspective transformations”, (Zacks, Mires et al. 2000). Object-based spatial transformations involve a person’s imagining transforming the object relative to the environment and the person. Perspective transformations involve a person’s imagining moving his/her personal point of view relative to the environment. The evidence from various strands of research supports the view that mental rotation and perspective taking are dissociated processes (e.g. Huttenlocher and Presson 1973; Presson 1982; Tversky, Kim et al. 1999; Zacks, Mires et al. 2000; Zacks, Vettel et al. 2003) and a person’s ability to mentally manipulate an object and imagine a scene from a different

viewpoint are dissociated mental abilities (Hegarty and Waller 2004). This implies that there could have been differences in the processes and abilities involved in these SSV participants imaginations of the sequences of different views in this task depending on which type of spatial transformation they employed.

In this study, participants' visualization performances were evaluated based on their drawings and descriptions of their visualizations of this building from a stationary viewpoint. But, if a research study would be conducted to explore individual differences in performance in carrying out such a task, (1) which would involve visualization of the sequences of different views of a building from different directions and (2) which participants would carry out by applying a SS visualization strategy, these possible differences in the way the participants could carry this task need to be taken into consideration.

Based on the observations made in the SSV architects visualization processes, the understanding I attained with regard to the features of these participants' 3D SS visualizations was as follows:

- SSV participants in response to being asked to visualize the building space(s)/form from the given locations, mainly visualized the building space/form in 3D SS from the side of the given location, much like imagining a partially open 3D small scale model of a space or a partial model of the building's mass. Some of these architects visualizations were fragmented in nature
- While %40 (2 of 5) of the SSV participants solely visualized the building's space(s)/form in 3D SS, %60 (3 of 5) of them had a more fragmented 3D SS visualization experience involving an intermittent episode of 3D LS visualization.
- These participants mainly visualized the spaces that one would see if one were to walk inside the various spaces of the building by imagining a 3D SS model

of the building either by imagining the spaces by following the order in which they would be encountered on a walk path or by focusing on different portions of the building without any specific order.

- In their visualizations of the appearance of B2 from different sides in the walking task these participants had partially different visuospatial experiences. Some imagined the different sides of the building by mentally rotating the model or imagining themselves rotating around the model whereas some others mainly imagined constructing discrete 3D SS models of the portions of the building that would be visible from different sides.

5.2 The Nature of the Mental Representations That Participants Created in Their 3D SS and LS Visualization Processes

5.2.1 The 3D LS Visualization Processes

In the occurrences of LS visualization, the participants were depicting the relative locations, shapes of the components most often along with their relative sizes and spatial relations among them as if they, at the time, were really situated inside or outside the visualized building or a LS model of it. Based on these participants' renderings of the space/form, it was possible to infer that these participants underlying mental representations in their LS visualization processes were 3D constructs which captured the 3D structure of the building space/form including the relative spatial locations, their spatial relations, their shapes and approximate dimensions.

As discussed in the previous chapter, these participants' 3D mental visualization performances were determined through an in depth analysis of information rendered in the drawings of their visualizations and any additional information they included in their descriptions of the visualizations. The focus of this analysis was on identifying whether the participants' could have captured (1) the components that would appear in their

drawings from the viewpoint taken, (2) their approximate relative spatial locations and relations and (3) their forms in terms of their shapes and approximate dimension proportions. In the context of this analysis it was seen that these participants rendered almost the same information in their drawings and verbal descriptions of their visualizations; and these participants in their drawings could have captured the components that would appear in that space/form to different extents and their spatial locations, relations, shapes and dimensions with varying levels of accuracy.

Based on the above observations, it I understand that:

- The mental representations of a building space/form that these participants create during their LS visualization processes were 3D visuospatial constructs with a spatial structure similar to the represented space/form much like a LS or real size model of that space/form. In these representations, the participants with varying levels of completeness and accuracy, captured
 - The relative spatial locations of the components in the building space/form and the spatial relations among them
 - Component forms including their 3D shapes and relative approximate dimensions

As discussed previously, two of the situations observed in this analysis were (1) %83 (5 of 6) of LSV participants' switching to SS visualization when describing the components which would most likely be partially or not visible from their current locations and (2) %75 (6 of 8) of these participants' misidentifying the component(s) that would be visible or not from the given location when visualizing them in 3D LS. One further aspect observed in these LSV participants visualizations of the buildings including these situations, was their frequently using expressions of possibility while describing their visualizations such that "I don't think I can see", "I would probably see" (A6) , "I think I cannot see that" (A10) , "probably you get to see", "I am thinking how

much you get to see when you are standing there” (A4), “If I see above I can see” (A6), or “doing like that (he looks above) I would see, I think” (A2).

Based on these observations, my understanding is that these participants knew that they should not be seeing some components or partially seeing some of them when looking at that building space/form from a particular location. Accordingly, they were trying to picture the building space or form as would be seen by the eye but, it was not quite possible to construct a view of the space as exactly as would be seen by the eye in their imaginations. This was why they were continuously using words expressing ‘possibility’ or ‘thinking’ at those moments. This was also why LSV participants were either switching to 3D SS visualization or not correctly identifying visibility of some of the components in the situations where the components would be very likely partially or fully blocked by a component at the front. In sum, I suggest that:

- What these participants captured in their mental representations during their large scale visualization processes was not like what would be captured from a specific viewpoint.

5.2.2 The 3D SS Visualization Processes

In the occurrences of SS visualization, the participants were mainly rendering an invisible 3D SS model of the building space/form by depicting the component shapes in their respective locations, the connections among the components and most often the relative dimensions in the way they would be in that SS model. Accordingly, it is possible to infer that the mental representations that these participants created during their 3D SS visualization processes were 3D constructs which had a structure similar to a 3D SS model of the represented space/form capturing the components relative locations, spatial relations, shapes and approximate dimensions.

In the context of the 3D mental visualization performance analysis, as in the cases of LS visualizing participants, it was seen that the information that the SSV participants

rendered in their drawings and verbal descriptions of their visualizations were almost the same; and these participants with varying levels of accuracy captured the 3D spatial arrangement of the components in their drawings of the visualized space/form including their relative locations, spatial relations, shapes and dimensions.

Based on these observations, I understand that:

- The mental representations of the building space(s)/form that participants created during their 3D SS visualization processes were visuospatial constructs with a spatial structure similar to that of a 3D SS model. In these representations the participants, with varying levels of completeness and accuracy, captured:
- The relative spatial locations of the components in the building space/form and the spatial relations among them
- Component forms including their 3D shapes and approximate dimensions

5.3 Construction of the Mental Representations Involved in 3D LS and SS

Visualization Processes

One common aspect observed in %72 of (8 of 11) participant's -involving both SSV and LSV participants- visualization processes across the various visualization tasks, was the instances of component defining. In these occurrences, the participants after locating a component in the rendered 3D small 3D LS space/form, produced gesture(s) where they depicted a formal attribute such as height, width or 2D/3D shape of the component outside its spatial context and sometimes in a scale different from that of the building.

Putting together these observed instances of component defining with the other aspects observed in these participants' renderings of their visualizations, what the participants were doing when visualizing a building space/form in 3D SS or LS can be summarized as follows:

- (1) they were mainly describing each of the components that they see in that space/form by depicting its location in the 3D space/form, its shape and dimensions and spatial relations with previously depicted components in their gesture spaces;
- (2) through the sequences of gestures they produce for depicting each component's location and other properties, they were mainly rendering a coherent 3D SS model or 3D LS model of the building space/form;
- (3) at some instants in the course of their descriptions, they were also all of a sudden focusing on an individual component that they located in 3D small or LS for a second and depicting its form attributes in their immediate gesture space outside that spatial context and in an independent scale;
- (4) in addition they were switching from their dominant form of visualization to other forms of visualization for intermittent episodes

What was very interesting in these participants' predominantly SS/LS visualization processes was that throughout their visualization processes they were rendering a coherent SS/LS model of the visualized building space/form in their gesture spaces even though they were interrupting their SS/LS visualization processes at some intervals by switching to other forms of visualizations or by focusing on visualizing a particular component outside its spatial context. For instance, in her predominantly LS visualization process, the participant until some point had been rendering a LS model of the visualized space in her gesture space. Then she switched to 3D SS visualization to visualize the arrangement of some components in that space in SS and rendered a SS model of those components in her gesture space. After she visualized the arrangement of those components in 3D SS, she returned to visualizing the space in 3D LS at the point where she left off. As she returned to 3D LS visualization, she continued to render the newly visualized portions of the space in her gesture space as if s/he never stopped rendering the LS model of the space or in other words as if the LS model of the whole

space/form had always been there. So that even though s/he stopped rendering this 3D LS model of the space for a while she was being able to return to rendering the rest of this model.

These participants, while rendering these coherent 3D SS or LS models of the visualized space/form throughout their visualization processes, were basically doing so in a component by component or part by part manner. They were describing the components that they see in the visualized building space/form and locating each component in their 3D SS or LS gesture models by depicting its dimensions and shape and depicting the geometry of its connection to the nearby components that they had already rendered in their gesture models. It might be possible to think that these participants had a complete 3D LS/SS model of the visualized building space/form in their mind but they were describing and rendering it in a component by component manner in their gesture spaces simply because of the sequential nature of speech. In other words, it was possible to think that these participants had initially constructed a 3D SS/LS model of the space/form in their minds as detailed as the way they rendered it through the course of their descriptions. Then during their descriptions they basically described and rendered this model in a component by component manner -by concurrently depicting each component in its spatial context and sometimes by depicting certain attributes of the component outside its spatial context. Yet such a line of thought would fail to explain the intermittent episodes of other forms of visualization that took place in the context of these participants LS or SS visualization processes. Most of these episodes as understood from their close examination were spontaneous occurrences that came to realization by various spontaneous considerations or difficulties. Some LSV participants, for instance, all of a sudden, were realizing that they were not clear about the 3D arrangement of some components in the visualized building space/form and turning from LS visualization to SS to figure out their arrangements. Likewise some SSV participants, after describing and visualizing the 3D layout of various components in the visualized space in 3D SS, were

all of a sudden realizing that some of the components would not be seen if they were to visualize the space from within from the given location and turning to LS visualization to determine whether that component would be visible from that location. Observing these occurrences, my understanding was that these participants were not basically initially constructing a 3D SS or LS model of the building space/form in their minds at the level of detail that they rendered it during their descriptions and what they did was not like describing a completely built model that they had in their minds in a component by component manner because of the sequential nature of speech.

Putting together all these observations made in these participants' predominantly LS and SS visualization processes, my interpretation and view is that these participants were mainly creating their underlying mental representations of the building space(s)/forms through an active construction process in the following way:

- They were first constructing a working memory (WM) representation of that building space/form or a specific portion of it; these representations were much like generic 3D frame-like¹² models of that space/form that captures the 3D spatial structure of that space/form with a structure similar to that of a 3D SS/LS model of that space/form. These frame-like models captured the relative spatial locations of the components in space, the proportional distances among the components and the proportional dimensions of the containing space/form with very silhouette like representations of the components but not the detailed appearances of the components or their relations with the nearby components.
- After they constructed their 3D frame-like models, they were encoding it into their long term memories (LTM) as the main scheme of the space.

¹² What I mean by "frame" here is to be distinguished from the notion of 'frame' as used in Artificial Intelligence as a form of LTM knowledge representation.

- Then while they were describing their visualizations in a component by component manner, they were beginning to fit more detailed representations of the components into this 3D frame-like model one at a time, in a stepwise fashion. Yet, most likely due to the capacity limitations of WM these participants were not simply adding more and more detail in to these 3D frame-like models and meanwhile were maintaining more and more detailed models throughout the visualization process in their WMs. They were plausibly continuously updating their LTM representations of these models as they go along throughout the process and were mainly maintaining their 3D generic frame-like models throughout their visualization processes. At the end of this process they were ending up with a detailed 3D SS or LS model of that space/form as encoded in their LTM.
- This way they were able to continue to consistently depict the spatial location of each component in their gesture spaces and render a coherent 3D SS or LS model of that described space/form throughout their descriptions, although there were the interruptions of the intermittent occurrences during which they visualized the 3D arrangement of some components in another form of visualization or focused on and visualize a single components outside its spatial context, and thereby during which they create different representations in their WM. In other words, having a LTM representation of their frame-like models, they were basically reconstructing these frame-like models in their WM after such intermittent episodes of other forms of visualization or instants of component visualization. This way they were being able to continue with a consistent 3D LS/SS model in their gesture spaces and add more detailed representations of the remaining components in a stepwise fashion.
- As they were fitting the detailed components in to this generic frame-like model once at a time, when they come to adding a component in to some

portion of the model in a detailed manner, they were all of a sudden realizing that they should not or they would not be able to do so, for instance, because that and some consecutive components need to be visualized from another perspective or they were not certain about the exact arrangement or appearance of that and some other components at that portion of the building space/form. Accordingly, they were sometimes skipping a component, or all of a sudden switching to another form of visualization, or focusing on that single component for an instant and modeling it outside its spatial context, and so forth.

- As they switch to another form of visualization for a short interval for visualizing the arrangement of some components in that space/form, they were going through the same process outlined here. They were first developing a generic spatial frame-like model of the portion of the building that involves those components and then were fitting the components into it one at a time. As they returned back from the other form of visualization to their dominant form of visualization, they were basically retrieving their 3D generic models and continuing to fit the remaining components in to it.

5.4 3D SS versus LS Visualizations of the Buildings

In the visualization tasks of this study the participants were asked to visualize what they would be seeing if they were to be looking at the building spaces and form from the given locations or while walking inside or outside them. In this respect the participants were basically required to visualize the buildings by situating themselves inside the building environment. Yet it was seen that only six of these participants, who were referred as the LSV participants, imagined the appearance of the building space(s) and form by situating themselves within the building environment. On the contrary, the five of these participants, who were referred as SSV participants, mainly imagined the

building space(s) or form from outside much like constructing or examining a SS scale model of the building or building space. These five participants visualizing the buildings in 3D SS was an interesting outcome considering that they were asked to visualize the building spaces and forms from within as LSV participants did. There are two plausible explanations for this outcome. First, these participants' could have resorted to 3D SS visualization because 3D SS visualization puts lesser demands on the cognitive processes and capacities than 3D LS visualization. Second, they could have resorted to 3D SS because 3D LS visualization relies on some set of abilities and processes that are not involved in 3D SS visualization and that were limited in the SSV participants. At this point the latter seems to be a more plausible explanation for some participants predominantly visualizing in 3D SS in this study than the former because if it was only differences on the demands they put on the cognitive resources, given the task requirements, the SSV architects at least would try to visualize in LS to a certain extent.

As outlined in the previous sections, there were a number of occasions at which these SSV and LSV participants were observed to switch to the other form of visualization at some short intervals of their verbal descriptions or while generating the drawings of their visualizations. These occasions and the inferences that I made in the examination of these occasions can be summarized as follows:

Switching from SS to LS visualization:

- (1) In their visualizations of B1's gallery space in task #3-B1-S, %60 (3 of 5) of SSV participants switched to LSV for visualizing the appearance of the guestroom slab and the skylight from the given location; they plausibly did so in order to capture and define whether or to what extent they would see the skylight behind the guestroom slab if they were to look at them from the given location.

Switching from LS to SS visualization:

- (2) %50 LSV (3 of 5) Participants switched to 3D -SS visualization when visualizing the 3D layout of the components which they were not clear about. In most cases these participants did this as a first step for imagining their appearance in 3D LS rather than directly trying to visualize them in 3D LS. These participants switched to 3D SS visualization in these situations plausibly because 3D SS visualization was a cognitively more affordable form of visualization than 3D LSV to which they can resort to for figuring out the unclear parts in 3D and because 3D SS was a more efficient form of visualization for figuring out unclear portions as it provides an overall apprehension of a large scale composition at once.
- (3) %83 (5 of 6) of the LSV participants switched to 3D SS visualization in the occasions where they were to describe the components that would most likely be partially visible or not visible from their current locations due to their being partially or fully obstructed by a closer component at the front. These participants in these occasions while visualizing the arrangement of the components in 3D SS verbally expressed that they should be seeing some in part. They resorted to 3D SS visualization in these occasions plausibly because it was difficult maybe impossible to visualize these components as would be seen from their current location in 3D LS.
- (4) %50 (3 of 6) of the LSV participants switched to 3D SS visualization to recap the spatial relations and connections among some of the components that they already rendered in their 3D LS of the space/form. They did so plausibly because 3D SS provided them an overall apprehension of the connections of these large scale entities that can not normally be apprehended at once.

Looking at these occurrences my overall understanding was that 3D SS-visualization in general was a more cognitively affordable form of visualization for these participants than 3D LS visualization. Due to this reason (1) the SSV-Participants mainly

visualized the building space/form in 3D-SS unless they think that it was critical to visualize them in 3D LS; (2) the LSV-Participants mainly chose to visualize an unclear portion of the building first in 3D-SS rather than trying to directly imagine it in 3D LS and (3) LSV-Participants turned to 3D-SS visualization as a substitute in cases where they have difficulty in visualizing the arrangement of components in 3D LS. I further understand that one other motivation for the LSV architects turning to 3D SS visualization was that it supports certain inferences more effectively than LS visualization, as observed in 2 and 4, by providing the opportunity to apprehend 3D arrangement and relations of multiple components, which are too large to be captured at a glance, at once.

CHAPTER 6

COMPARATIVE ANALYSES OF ARCHITECTURE

PARTICIPANTS' DRAWINGS

The previous chapter outlined the analysis of the visualization protocols of the architecture participants which was conducted with the aim of developing an understanding about the features of the architects' 3D mental visualizations in the various tasks and the nature of the mental representations that are created in these visualization processes. This chapter outlines the comparative analyses which were conducted on the drawings, which architecture participants, hereafter called participants, generated in the context of this study to gain insights about the nature of the mental representations that they constructed during their visualization processes.

These comparative analyses were conducted on different sets of drawings with different incentives. In the first analysis two types of drawings were compared. The first type was the drawings of the actual building space (ABS) that the participants generated in the perspective drawing task; in this task they were taken to the gallery space of their department buildings, West Architecture Building, and requested to draw a perspective view this space by looking at it from the specified location. In this task they were told that they were not expected to generate a very detailed perspective drawing of the space but rather a rough one that can be captured in around 10 minutes (though it should be mentioned that some participants wanted to take more time to add more details to their drawings). The second was on the drawings that the participants generated in the course of two 3D mental visualization tasks. These were the tasks #3-B1-S and #1-B2-S where the participants, after they completed their descriptions of their visualizations, were requested to draw their visualizations of the B1's gallery space from location 3, and B2's

exterior form from location 1¹³. In the comparative analyses of the drawings of the ABS and mental visualizations, the objective was to develop an understanding about whether what participants captured in their 3D mental visualizations of a building space/form from a certain viewpoint would be similar to what would be captured in that space/form when looked at from a specific viewpoint. In this analysis these drawings were mainly examined based on a number of characteristics which included (1) the location and direction of the viewpoint taken, (2) the approximate relative proportions of the components and the containing space/form and (3) visibility of the depicted components from the given locations.

In the second comparative analysis three types of drawings were cross examined. The first type was the participants' drawings of the ABS. The second was the drawings that they generated in their 3D mental visualization. In this analyses these three types of drawings were briefly examined to explore whether there might be any feature common to the drawings that these participants generated from imagination, i.e. drawings of their mental visualizations and the RBS, but not to the drawings they generated by actually looking at a building space i.e. drawings of the ABS.

In this study one of the decisions made in the development of the procedure was that the participants would not be requested to generate a perspective drawing of the RBS and the visualized gallery space of B1 and the exterior form of B2 unless they ask about in what form they should draw them. At this point, it should be noted that all the participants either directly mentioned that they were going to generate a perspective drawing or asked about whether they should draw the RBS and/or the visualized building space/form in perspective. In these cases they were told that they should¹⁴. Accordingly it

¹³ The participants, at the time they were given their visualization tasks, had been shown these locations and the direction which they should be oriented towards by means of an empty plan of the ground floor in B1 and a symbolic foot print of B2 on the site.

¹⁴ Some participants after starting to draw the building space/composition from a different perspective asked if they should have been drawing an eye-level perspective; in these cases the participants were told they should have and requested to do so if possible.

should be noted that all the drawings that will be presented in the context of this discussion were generated by the participants either with the intention to generate or the knowledge that they should generate a perspective drawing of the visualized space/form as would be seen from the given locations.

6.1 Comparative Analysis of the Participants' Drawings of the Mentally Visualized Building Space/Form and ABS

As discussed in Chapter 5, in the analysis conducted on the participants' visualization protocols of the 3D mental visualization tasks, a distinction was found among the participants with regard to the form in which they predominantly visualized the building space(s)/forms. It was seen that six of these participants had predominantly visualized the building space(s)/forms in 3D LS in all visualization tasks, whereas five had predominantly visualized the building space(s) forms in 3D SS. Since the comparative analysis of the drawings aimed at understanding the nature of the mental representations that architects created during their visualization processes and that informed the generation of these drawings, in this analysis, the LSV and SSV drawings' were examined and discussed in separate sections.

Two of the participants' visualization protocols could not be examined in the previous analysis due to their producing very minimal number of gestures. These two participants' drawings were included in this analysis. The outcomes obtained from them, which were taken into consideration in the interpretations made, were very similar to the outcomes obtained from the SSV and LSV participants' drawings. So these outcomes will not be discussed separately in this chapter.

6.1.1 The Comparative Analysis of LSV Participants' Drawings

The first aspect examined in the comparative analysis of the drawings was the location and direction of the viewpoint taken by these LSV participants in their

depictions of the mentally visualized building space/form and the actual building space. Here the objective was to examine whether these participants, as requested, were able to depict the appearance of mentally visualized interior space of B1 and exterior form of B2 and the ABS approximately from the given viewpoint location in the given direction. At this stage, the focus was mainly on the ‘location and direction of the viewpoint’ not on whether or what extent these participants were able to depict the appearance of space/form ‘as would be seen from the given or self adapted viewpoint’.

In this part of the analysis, as can be seen in the examples presented in Figure 29 and Figure 30, the participants’ drawings of the ABS, were examined with reference to the picture of that space in order to identify whether each of these participants could approximately depicted this space from the given viewpoint location and direction. Each participant’s drawings of the B1’s interior gallery space and B2’s exterior form were mainly examined by capturing the closest views to the ones depicted by the participant from the computer models of these buildings. The location and direction of the viewpoint in the closest computer views were identified (1) to determine the approximate location and direction of the viewpoint adapted by the participant in his/her drawing and (2) thereby to determine whether the participant was able to depict the appearance of the building space/form from the given viewpoint location in the given direction. It was seen that all these participants’ were able to approximately depict the ABS from the given location in the given direction. On the contrary, as summarized in Table 16, it was seen that:

- %50 (3 of 6) of these participants in their drawings of B1 and %66 of them in their drawings of B2, generated views that cannot be captured from a single viewpoint; in these drawings, as can be seen in A2’s drawing of the B1’s interior space in Figure 29, and A9’s drawing of B2 in Figure 30, the drawings participants generated incorporate component views taken from different viewpoints at different positions on the floor layouts and heights.

- % 33 (2 of 6) of the participants in their drawings of B1 and % 33 (2 of 6) in their drawings of B2 were able to depict the building space/form almost¹⁵ from a single viewpoint, as can be seen in architect A9's drawing of the B1's interior space in Figure 30. However these participants, except from A4's drawing of B1's interior space, did not approximately depict the space/form from given viewpoint location and /or height. For instance in Figure 30, the closest view to the participant's drawing of his mental visualization of B2's exterior form was captured from a viewpoint which is located 2 meters above the height of the given viewpoint and 5 meters away from the given location towards the east (right side of the current corner).
- % 16 (1 of 6) of the participants in his drawing of B1 was able to depict the building space/form almost from the given viewpoint.

Table 16 Observed characteristics in LSV participants' drawings of B1 and B2

Part #	Drawings of B1					Drawings of B2				
	G. VP	S.VP	M. VP	Non Viz.	Rel. Prop	G. VP	S.VP	M. VP	Non Viz.	Rel. Prop
A2	No	No	Yes	NA	Close	No	Yes	No	Yes	No
A4	Yes	Yes	No	Yes	Close	No	Yes	No	Yes	Close
A-6	No	No	Yes	Yes	No	No	No	Yes	NA	No
A-8	No	No	Yes	NA	No	No	No	Yes	NA	No
A-9	No	Yes	No	Yes	No	No	No	Yes	NA	Close
A-10	No	Yes	No	Yes	No	No	Yes	No	Yes	No
Abbreviations & explanations: G.: given; VP: view point; S: single; M. : multiple; Non.Viz: existence of normally non visible components in the drawings; Rel. Prop: whether these drawings captured the relative proportions in the extent that the drawings of the ABS did.										

¹⁵ As will be discussed, one further aspect to be looked at in these drawings was their capturing the visible components or excluding the not visible ones from the given location. Normally incorporating a component that could only be visible from a different height or location would indicate a second viewpoint. Here the term “almost” is used in reference to cases where the building space/form was to a large extent depicted from a single viewpoint expect for existence of a component that would normally not be visible from that viewpoint height or location.

Overall, it was seen that all the participants were able to depict the ABS approximately from the 'given viewpoint location and direction', however %83 (5 of 6) of these participants in their drawings of B1 and %100 (6 of 6) of these participants in their drawings of B2 were not able to depict the visualized building space/form from the 'given viewpoint locations and directions'.

The second aspect to be investigated in the comparative analysis of the drawings was the approximate relative proportions. Here the term 'relative proportions' is used in reference to the two major characteristics of a perspective drawing which represents a scene from a single viewpoint: (1) as the distance between the point of view and the objects in a scene increases, the objects appear smaller (2) the objects' internal dimensions become disproportioned, the dimensions that are parallel to the line of sight appears relatively smaller than the dimensions that are angular or parallel to the line of sight. The objective here was to determine whether the participants were able to depict the approximate relative proportions of the components and the containing space/form in their drawings of their mental visualizations from the given/adapted viewpoints to the extent that they were able to do so in their drawings of the actual space. In this part of the analysis, the drawings of the actual space were again examined on the basis of the picture taken from the given viewpoint in this space. The drawings of the few participants where the building space/form was depicted from a single viewpoint were examined on the basis of the closest view generated. In the drawings, where the participants depicted different parts or components of the space/form from different viewpoints, the relative proportions were examined generically on the basis of the multiple closest views, mostly in terms the depiction of the relative sizes of the components that are at different distances. In these drawings the disproportioning of the components along the multiple sightlines were mainly looked at for the salient ones that can be discerned.

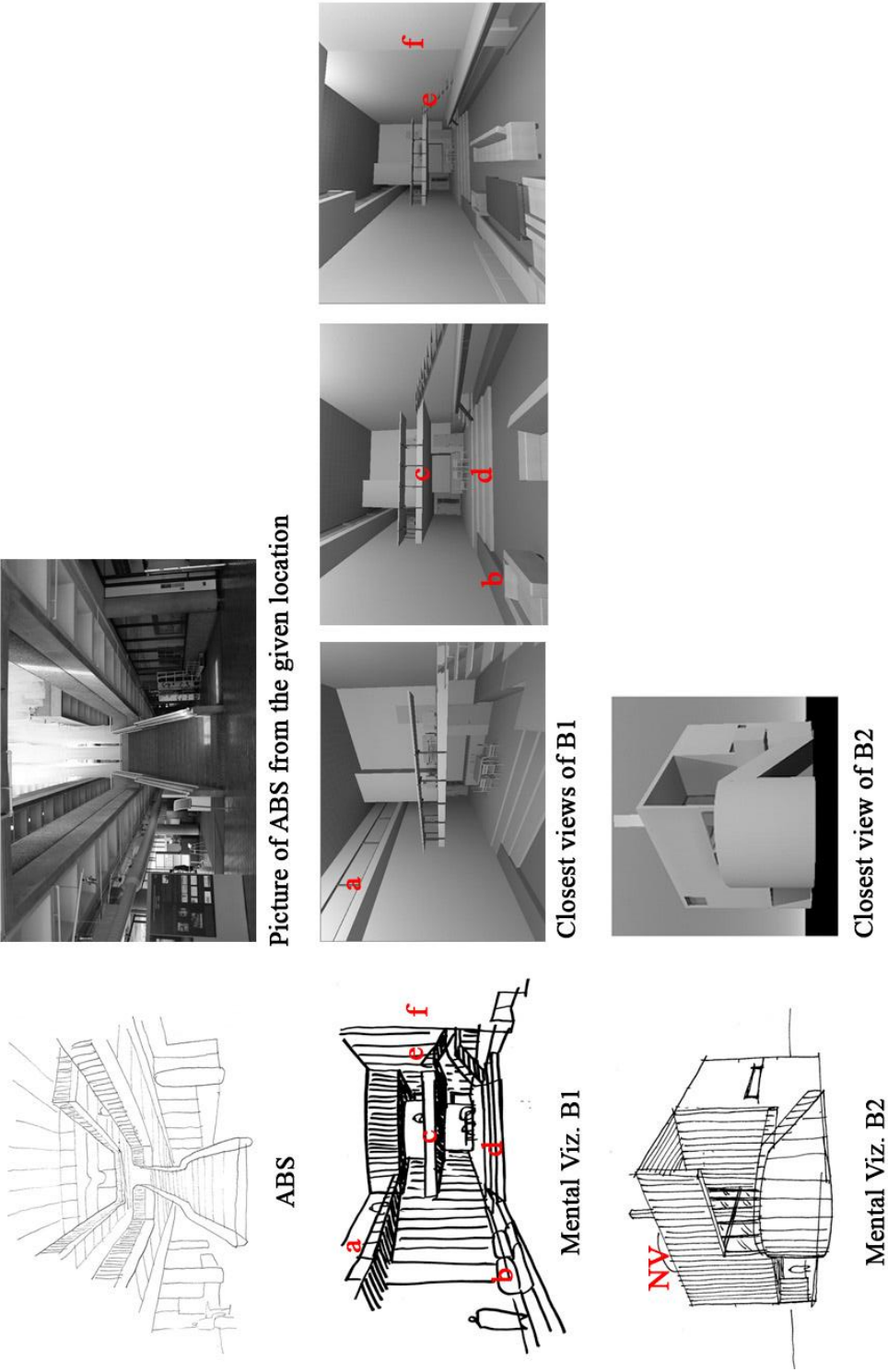


Figure 29 Examination of the locations of the viewpoints in A2's drawings. The same letters in the drawings and closest views represent the portions/components of the building space/form that are depicted from the same viewpoint in the drawing and that closest view.



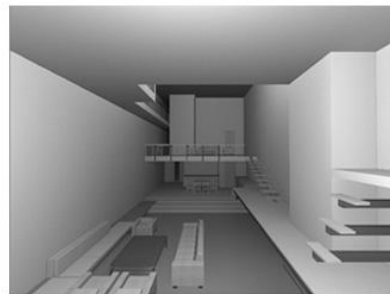
ABS



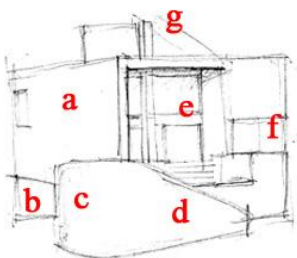
Picture of ABS from the given location



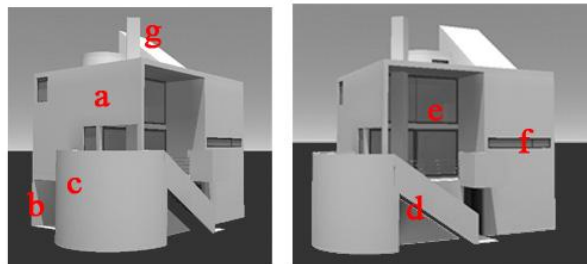
Mental Viz. B1



Closest view of B1



Mental Viz. B2



Closest views of B2

Figure 30 Examination of the locations of the viewpoints in A9's drawings. The same letters in the drawings and closest views represent the portions/components of the building space/form that are depicted from the same viewpoint in the drawing and that closest view.

In this part of the comparative analysis, as summarized in Table 16, it was seen that, % 66 (4 of 6) of these participants in their drawings of B1 and %66 (4 of 6) in their drawings of B2 were not able to capture the approximate relative proportions in their drawings of mental visualizations to the same extent that they were able to in their drawings of the ABS. For instance, as can be seen in participant A9's drawing of his mental visualization of the interior space of B1 in Figure 30, in most of these participants' drawing of Building 1's interior space, the depth of the living room space and the size of components that run along the living room such as the bridge or the side platforms were represented either shorter or longer than they would appear in the drawings. The closest components, the fireplace and the side stair were not depicted as relatively large as they would be seen from that location, or the side platforms which would be seen much larger as they become closer were not depicted in that way in the drawings. Likewise in most of these participants' drawings of the building's exterior form such as in participant A2's drawing in Figure 29, the size of the half cylindrical study wall room and the stairs connecting to them were not depicted as relatively large as they would appear when looked at from the given/adapted location. In some the side façade walls or the walls that define the void over the balcony were depicted longer/shorter in length or higher/shorter in height than they would appear from the given location. Among these participants, % 33 (2 of 6) in their drawings of B1, and %33 (2 of 6) in their drawings of B2 were found to be able to capture the approximate relative proportions in their drawings of mental visualizations in an extent closer to that they were able to in their drawings of the ABS.

The last aspect that was aimed to be examined in this analysis was the visibility of the depicted components from the given or adapted viewpoints. Normally when people look at a building space/form their view of some of the components in that space/form would be blocked by the components at the front depending on the viewpoint taken. Accordingly these components would not be visible from the taken viewpoint. The

objective here was to determine whether the participants in these various drawings of mental visualizations and the actual building space were able to capture the appearance of the building space/form from the adapted or given viewpoint in the same extent in terms of not including the originally non visible¹⁶ components in their drawings. As outlined above, various participants had adapted multiple viewpoints in their drawings. In these cases it would not be feasible to examine whether they correctly excluded the non visible components from their drawings. One exception would be the cases where a component would not normally be visible from any of the multiple viewpoints.

In this part of the comparative analysis, it was seen that %100 (6 of 6) of these participants did not include the normally non-visible components in their drawings of the ABS. On the contrary, %100 (4 of 4) of the participants, who depicted the interior space of B1 and/or exterior form of B2 from a single viewpoint, such as A2's in his drawing of B2 in Figure 29 , did include non-visible component(s) in their drawings. It was further seen that one participant (A6), who adopted multiple viewpoints in her drawing of B1, included a component that would not be captured from any of the adopted viewpoints.

Overall, in each of these LSV participants drawings' of the mentally visualized space/form two or all of the following were observed:

- The participant was not able to depict the space/form from the given location although s/he could in the drawing of the ABS.
- The participant could not capture the relative proportions in the extent they could in their drawings of an actual building space from the given location.
- The participant depicted one or more normally invisible components in their drawings of their mental visualizations but not in that of ABS.

¹⁶ There was the possibility that the participants had included the non visible components because their visualizations did not involve the components that would normally block these components and make them non visible. If such a case had occurred the participants' verbal descriptions would have been referred to identify whether they specified the blocking component in their verbal descriptions. If they had specified the blocking component, then the invisible components that the participants had incorporated into their drawings would have been considered as the components that should have not been included in the drawings because they should not be normally seen.

Accordingly my understanding is that:

- What these participants captured in the mental representations they created during their 3D LS visualization processes of a building space/form from a certain location was not like what would be captured when looking at that space/form from a certain viewpoint.

The evidence for this is as follows. Although all these LSV participants were able to depict the actual space as would be seen from the ‘given location and direction’, most of these participants were not able to depict the visualized space and building form from the ‘given locations and/or directions. Even though the participants were able to depict their visualizations almost from a single viewpoint, they were not able to capture the relative proportions as they could in their drawings of ABS and/or determine whether a component would be visible from a certain viewpoint as they could in their drawings of the ABS. This was also why overall %66 (4 of 6) of the participants in their depictions of their mental visualizations in one or both drawings drew them as a collage of portions of two or more drawings with different viewpoints.

6.1.2 The Comparative Analysis of SSV Participants’ Drawings

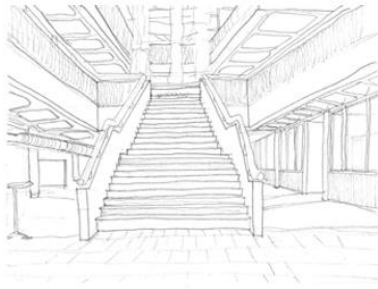
As summarized in Table 17 in the examination of these SSV participants’ drawings with regard to the location and direction of the viewpoint taken, it was seen that all these participants were able to depict the appearance of the ABS from the given location in the given direction. On the contrary, %100 (5 of 5) of these SSV participants both in their drawings of B1 and B2 could not depict the mentally visualized building space/form from the given locations. Indeed % 100 (5 of 5) of these participants depicted the interior space of B1 from multiple viewpoints rather than a single viewpoint (as can be seen in the examples in Figure 31 and Figure 32). In their drawings of B2, %60 (3 of 5) of them depicted the B2’s form from multiple viewpoints (such as A1 in Figure 31) and the remaining %40 (2 of 5) drew an axonometric projection of the B2’s exterior mass

(Figure 32). As can be seen in her drawings of B2 in Figure 32, A3 initially drew an axonometric view of the building and then generated the perspective drawing of the building. Both views are taken into consideration in the analysis, but here her drawing is listed as axonometric because this was the initial drawing she generated from her mental visualization of the building.

Table 17 Observed characteristics in SSV participants' drawings of B1 and B2

	Drawings of B1					Drawings of B2				
Part #	G. VP	S.VP	M. VP	Non Viz.	Rel. Prop	G. VP	S.VP	M. VP	Non Viz.	Rel. Prop
A1	No	No	Yes	NA	Close	No	No	Yes	Yes	No
A-3	No	No	Yes	NA	No	No	No	Yes	NA	No
A-7	No	No	Yes	Yes	No	NA	NA	Axon.	NA	NA
A-11	No	No	Yes	NA	No	No	No	Yes	Yes	No
A-12	No	No	Yes	Yes	No	NA	NA	Axon.	NA	NA

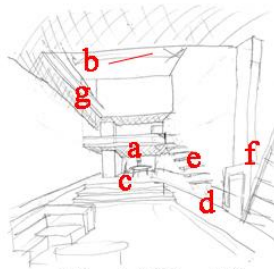
In the examination of the SSV participants' drawings with regard to relative proportions of the components and the containing space/form, it was seen that % 100 (5 of 5) of these participants in their drawings of B1 and %80 (4 of 5) of the participants in their drawings of B2 their mental visualizations were not able to capture the approximate proportions in the extent that they could in their drawings of the ABS. It was seen that %20 (1 of 5) of these participants was able to capture the approximate relative proportions in the drawing of B2's exterior form in an extent closer to that in the drawing of the ABS.



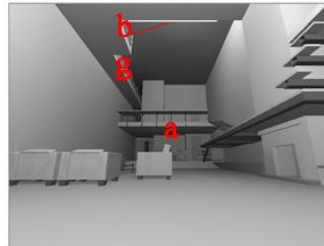
ABS



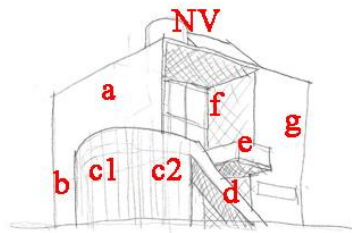
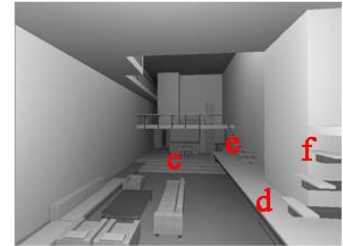
Picture of ABS from the given location



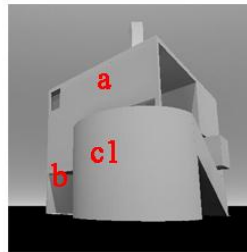
Mental Viz. B1



Closest views of B1



Mental Viz. B2



Closest views of B2

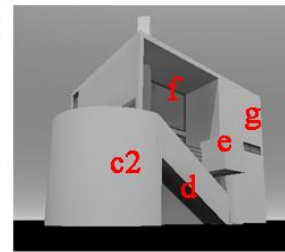


Figure 31 Examination of the locations of the viewpoints in A1's drawings. The same letters in the drawings and closest views represent the portions/components of the building space/form that are depicted from the same viewpoint in the drawing and that closest view.

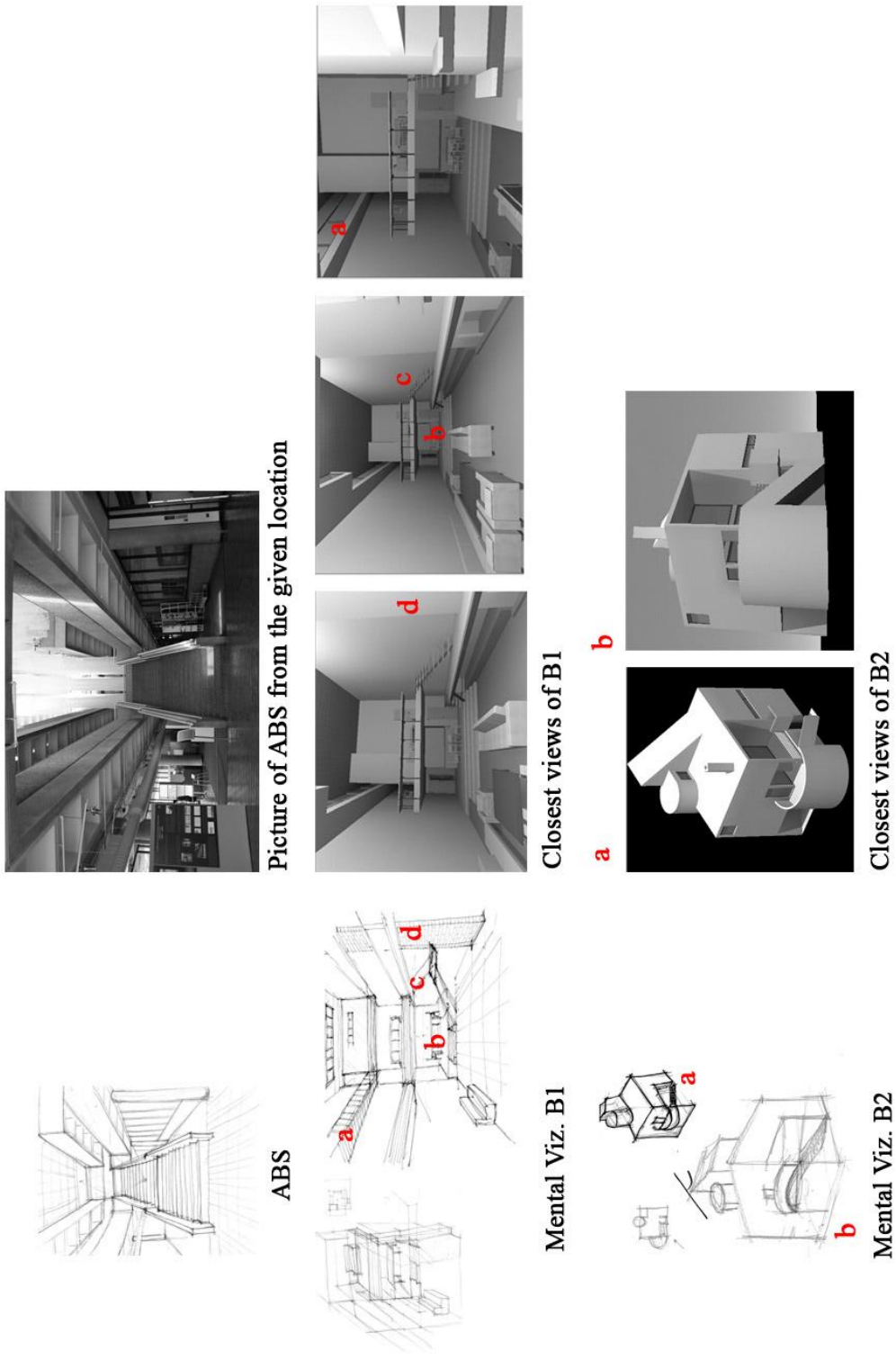


Figure 32 Examination of the locations of the viewpoints in A3's drawings. The same letters in the drawings and closest views represent the portions/components of the building space/form that are depicted from the same viewpoint in the drawing and that closest view

Since none of the SSV participants depicted the visualized building space/form from a single viewpoint, it was not feasible to examine whether they had included any of the normally non-visible components in their drawings. In the examination of the non-visible components, the drawings that participants generated from multiple viewpoints (not the axonometric drawings) were examined to see whether they depicted any component that would normally not be visible from any of the adapted multiple viewpoints. It was seen that %80 (4 of 5) of these participants either in their drawings of B1 or B2 depicted a non-visible component in their drawings. On the contrary, when these SSV participants' drawings of the ABS space are examined it was seen that %100 (5 of 5) of these participants did not include any normally non-visible component in their drawings of the ABS.

Overall it was seen that none of the SSV participants were able to depict the mental visualized building space/form from the given location although they could in their drawings of the ABS. Furthermore, in each of these participants' drawings one or both of the following were observed:

- The participant could not capture the relative proportions in the extent they could in their drawings of an actual building space from the given location
- The participant depicted one or more normally invisible components in their drawings of their mental visualizations but not in that of ABS

Furthermore, 40 % (2 of 5) of these participants mainly depicted their visualizations of the exterior form of the building 2 in axonometric projection rather than in perspective. Accordingly, my understanding was as that:

- What these participants captured in the mental representations they created during their 3D SS visualization processes of a building space/form were not like what would be captured when looking at a 3D SS model of a building from a certain viewpoint.

6.2 Comparative Analysis of the Participants' Drawings of the Mentally Visualized Building Space/Form, ABS and RBS

In this comparative analysis which was mainly conducted by visually examining the participants' drawings of the ABS, RBS and their mental visualizations, as in the examples presented in Figure 33, it appeared that most of these participants (%80) were more similar to their drawings of their mental visualizations than their drawings of the ABS in terms their general characteristics as well as their being drawn from the altered viewpoints and their capturing the relative proportions. %20 of these participants drawings were closer to their drawings of the ABS in terms of their general characteristics, their capturing the space almost from the given viewpoint location and the way the proportions are captured. Prior to being asked to recall and imagine the appearance of the common familiar space, all participants were asked whether they had worked with any 2D drawings of the space before and it was learnt that none of them had, which means that their knowledge of this space was mainly experience based. These participants might have had different visuospatial experiences of the RBS even to the extent that they could have really looked at that space many times exactly from the given location. It was also possible that they had never captured the asked view of this RBS. Furthermore it is possible that they had paid attention to different aspects of this space during their daily experiences in it and had developed different mental representations of this space from which they constructed their imaginations of the space from the given location. Given these many various possible differences among the nature of the sources of information on the basis of which these participants might have imagined the appearance of the RBS, and that the participants mainly constructed their 3D mental visualizations based on the 2D drawings of the buildings, it was quite surprising to see how similar these drawings of their mental visualizations and RBS were qualitatively. Particularly, %80 of these participants' drawings was similar to those of their mental

visualizations in terms of being captured from altered viewpoints. This observation was quite interesting leading me to consider that it might not only difficult, but maybe impossible to construct mentally a view of a 3D building space/form as would be captured from a single viewpoint. I suspect that especially in practices where people imagine the appearance of a 3D environment based on indirect information such as the two cases here, this could be the case. This needs to be further investigated and can provide important insights about such capabilities of the human cognitive system.

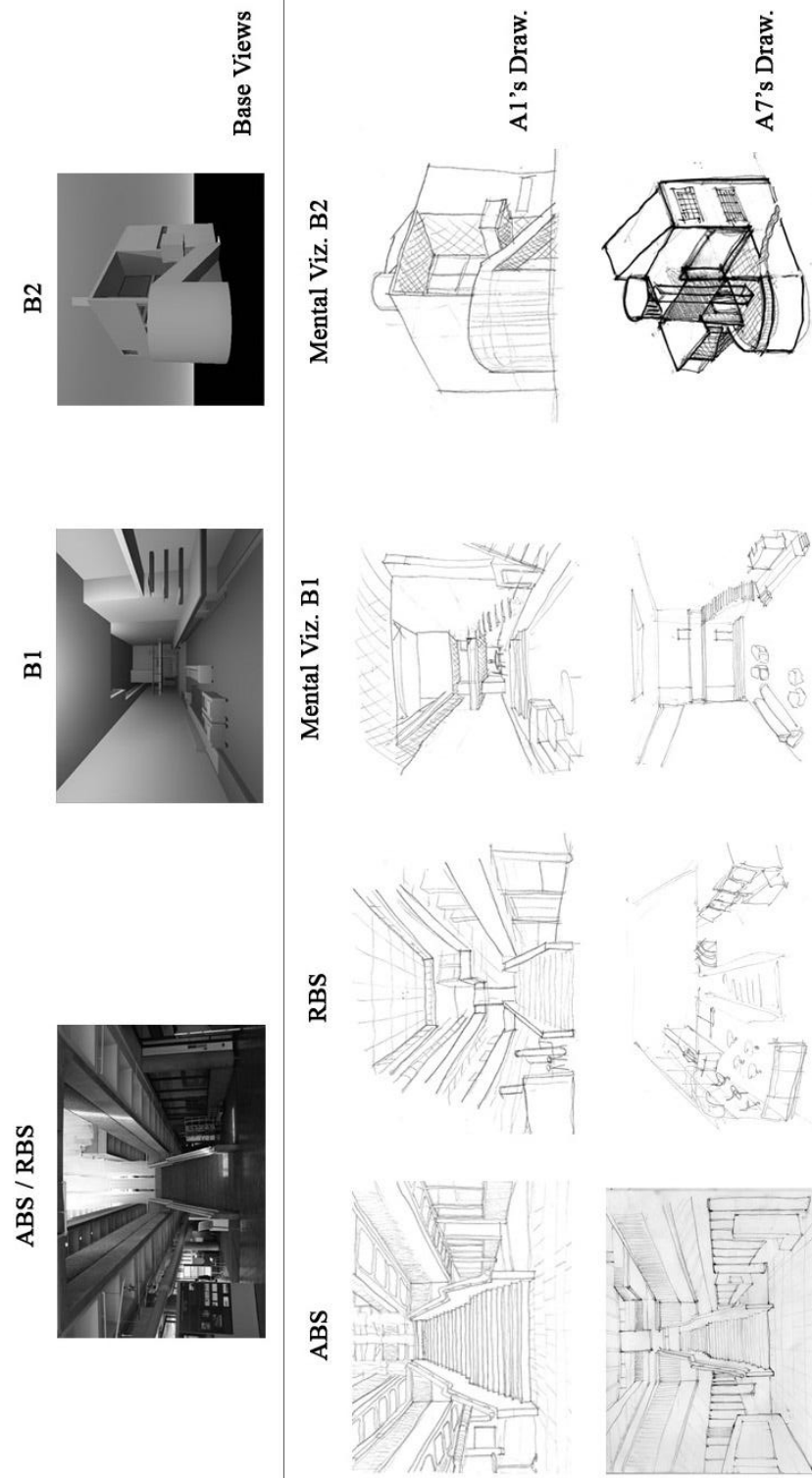


Figure 33 Cross examination of the drawings generated from imagination and perception

CHAPTER 7

FINDINGS AND IMPLICATIONS

This chapter discusses the findings of this study and their implications for architectural education and practice and for cognitive science research. It first discusses the findings in association with the research questions that I aimed to address through this study and outlines the implications of these findings for architectural design education and practice. It then discusses the implications of these findings for cognitive science research.

7.1 Nature of 3D Mental Visualization Phenomenon

The first research question in this study aimed at understanding the nature of the 3D mental visualization phenomenon that architects claim to experience when looking at 2D drawing or sketches of a building design or their design ideas. The question was:

- (1) What is the nature of the 3D mental visualization phenomenon architects claim to experience when imagining a building space/form or walking inside/outside a building?
 - a. What are the features of these 3D mental visualization processes/practices as evidenced in specific tasks?
 - b. What might be the nature of the mental representations that are created during these visualization processes?

In the following, I will first summarize and discuss the observations that were made with regard to the features of architects' visualizations to address the first part of this question (Q-1a). Then I will outline and discuss my observations and inferences about the nature of the underlying mental representations that architects constructed

during their visualization processes to address the second part of this research question (Q-1b).

7.1.1 Q-1a: Features of 3D Mental Visualizations

In this study the participants mainly carried out two types of 3D mental visualization tasks after studying the 2D drawings of two different buildings. In the first type of tasks -2-B1-S, 3-B1-S and 1-B2-S, they were required to mentally visualize a building space/form by imagining themselves standing at a certain location inside/outside the building. In the second type of tasks -1-B1-W and 2-B2-W, they were required to mentally visualize the buildings by imagining themselves walking inside or around the building.

A major observation in the analyses of the architects' 3D mental visualization protocols was that the architects, in all the tasks, had predominantly visualized the building space(s)/form in one of the two forms. 6 of these architects had predominantly visualized them in 3D LS, as if they were situated within the actual size (almost the actual size) building environment, while 5 of these architects had predominantly visualized them in 3D SS as if they were imagining a 3D small scale model of the building space(s)/form.

LSV Architects' Visualizations of the Building Spaces or Form

The LSV architects, when carrying out the walking tasks, imagined themselves much like teleporting or jumping from one location to a subsequent location on a path with a series of stopping locations on it rather than imagining themselves walking; they visualized the surrounding space or the building form predominantly in 3D LS from each of these locations in a motionless manner in the same way they did in the standing tasks. While predominantly visualizing the building space/forms in 3D LS, there were intermittent episodes of other forms of visualization in all these architects' imaginations

of the building in some of the visualization tasks. All these architects switched to 3D SS visualization in one or more of the standing or walking tasks under one or more of the three commonly found circumstances. These include the situations (1) where there was the possibility that some of the components in the visualized building space/form would be partially or not visible from their current locations due to a closer component's possibly blocking their visibilities, (2) where they were not clear about the 3D arrangement of some of the components and (3) where they were recapping the spatial relations and connections among some of the components that they already rendered in their 3D LS visualizations of the space/form. They switched to 2D SS visualization in one or both of the walking tasks in the situations where they were about to change or in the process of changing their relative positions on the building's floor/site layout.

Based on the observed patterns in these LSV architects visualization protocols across walking and standing tasks, I understand that what these LSV architects experienced while visualizing the building spaces and forms from the stationary locations was not a continuous LS visualization experience; rather they were alternating experiences blended with intermittent episodes of 3D SS visualization. What they experienced in their imaginations of walking was not like the continuous visuospatial experience of walking; rather they were much like a collage of sequences of the experiences of 3D LS visualizations of the various spaces/sides of the building imagined from stationary locations on a path occasionally blended with some experiences of 2D SS visualizations of (certain portions) the layout of the floor or building on site and 3D SS visualizations of the certain portions of the building space/form.

SSV Architects' Visualizations of the Building Spaces or Form

The SSV architects, when carrying out in the standing tasks, mainly visualized the building space/form in 3D SS, much like imagining partial SS model of that portion of the building, from the side of the location at which they were originally asked to imagine

themselves standing at. Some of these architects, when visualizing the B1's in interior space in one of the standing tasks, switched to 3D LS visualization for a short duration while visualizing the components in the cases where one of the components at the front would very likely partially or totally block the visibility the other when looked at from the given location. When carrying out these tasks that require imagining walking, the SSV architects, in their visualizations of the B1's interior spaces, mainly visualized and described a SS model of the overall building from a single self selected direction. When imagining inspecting or constructing a 3D SS model of the building some did so by following the order of the spaces to be encountered on a walk path whereas others did by focusing on different portions of the building without any specific order. In their visualizations of B2's exterior form these architects mainly imagined the appearance of the different sides of the building, which they would encounter if they were to be walking around the building, in one of the three different ways. These included (1) imagining themselves rotating a 3D SS model of the overall building (2) imagining themselves moving around and inspecting a SS model of the building from different directions and (3) imagining discrete partial SS models which were much like models that involve the components of the building which one would apprehend when looking at a SS model of the building from a certain direction.

All these architects, in the various visualization tasks, were mainly imagining a 3D small scale model of the visualized portions of the building; yet, I understand that there were some differences between the visuospatial experiences they had in two of these tasks. In their visualizations of the interior space of B1, some of these architects' had a continuous 3D SS visualization experience while others had a more fragmented one blended with the experience of 3D LS visualization of some portions of the space from a certain location. In their visualizations of the appearance of B2 from different sides in the walking task, although all were visualizing in 3D SS, these architects had partially different visuospatial experiences. Some imagined the different sides of the building by

mentally rotating the model or imagining themselves rotating around the model whereas some others mainly imagined constructing discrete 3D SS models of the portions of the building that would be visible from different sides. On the basis of the findings of the previous studies, I further understand that these architects in former cases relied on some dissociated processes which were most likely not involved in the latter case. Thus they not only had partially different visualization experiences but also their 3D SS visualization processes involved some dissociated capacities and processes.

7.1.2 Q-1b: Natures of Mental Representations

Based on the analyses conducted in this study, I understand that the mental representations that the architects created during their 3D SS or LS visualization processes had a spatial structure similar to that of the SS or LS model of the visualized building space/form. These mental representations captured information about the relative spatial locations of the building components in 3D space, spatial relations between them, 3D shapes and relative approximate dimensions of the components, and the containing space/form. The way these architects captured the various visuospatial aspects of the visualized building space/form in their mental representations during their 3D SS or LS visualization processes was not like the way they would be captured in a SS or LS model of that space/form from a certain viewpoint. Furthermore, it is understood that it could not be possible to capture the appearance of a 3D building space/form in imagination in the way it would be captured from a specific viewpoint at least in the cases where that building space is not represented from such a specific viewpoint.

Considering the above characteristics of these mental representations in conjunction with the inferences made with regard to process through which these mental representations were constructed as I will outline below, I propose that these mental representations can best be characterized as ‘perceptual mental models’ (Nersessian 2008) and the 3D mental visualization processes in which they are constructed can be

characterized as mental modeling practices. In order to explicate my proposal, I will first define the notion of mental model as commonly recognized in research in mental modeling during reasoning and then outline what a perceptual mental model means on the basis of characteristics of ‘perceptual mental models’ (Nersessian 2008).

There are mainly two aspects central to the notion of mental models. One is their being temporary structures¹⁷ that people construct and manipulate or revise in WM during various thinking processes. The other is their being schematic representations of real-world or imaginary objects, situations, events or processes capturing only the aspects of the referent, or what is represented, that are salient for the process carried out at the moment. This means that the information captured in one’s mental model can vary substantially depending on the aspects that are aimed to be reasoned about or understood at that moment. For instance, if one is asked about what the relative directions of various objects in a familiar building space are, she could construct a mental model which captures the various objects and their relative spatial directions in the space as a set of nodes spread in 3D space around a central node (the self), much like a nodes and line diagram where nodes are connected with lines in 3D, to report about their relative directions. Here, her mental model does not need to capture other information such as the exact locations of the objects in space or the distances between them because they are not required for the task at hand; thus this node and line diagram like representation does not need to correspond to the scale of space or the lines do not need to be proportioned based on the relative distances. If one is asked about what would be the relative locations of various elements in a familiar space when standing at a certain location, what they look like, and how far they would be, she could construct a mental model which captures the

¹⁷ In cognitive science literature term ‘mental model’ is also used to refer to a structure in long term memory ;in this line of research the focus has been on understanding the organization of knowledge in a domain in these long term memory representations and the role they play in supporting understanding and reasoning. In the context of this discussion, the term ‘mental model’ will be used in reference to temporary structure created during reasoning and comprehension processes.

3D spatial arrangement of the components, their distances and their shapes, colors, materials, etc with a spatial structure similar to that of these elements in the space.

‘Perceptual mental models’ are characterized by Nersessian (2008) in her analyses and account of the kinds of mental modeling practices in scientific reasoning, specifically those which employ analogical modeling, visual modeling and thought experimenting. Nersessian in her WM account of mental models defines a mental model as a “structural, behavioral, or functional analog representation of a real-world or imaginary situation, event, or process” (p.93). She proposes that " in certain problem tasks, people reason by constructing an internal iconic model of the situations, events and processes that in dynamic cases can be manipulated through simulation” (p.128). She underlines that these iconic models comprise modal, or perception based, constituents, and defines such models as “perceptual mental models’. Thus there are mainly characteristics that are specific to perceptual mental models. First, they are iconic representations; this means that they represent the captured aspects of a real-world or imaginary situation, event or process, demonstratively in an analogous way by preserving the constraints inherent in what they represent. For instance, the mental models in the examples above can be characterized as iconic representations as both capture the spatial relations between the objects and the self analogously by preserving their relative directions in space. Second, perceptual models are largely constituted by modal symbols which are analogs to the perceptual states that are extracted during perceptual processes, such as table being represented by retaining its perceptual aspects such as its shape, rather than with an amodal symbol such as ‘T’. Nersessian also underlines that in construction, manipulation and revision of perceptual mental models, one can utilize various kinds, formats (linguistic, formulaic, imagistic), and sources (external and internal) of information.

A major interpretation in my study, which led to consideration of the mental representations that architects created during their LS and SS visualization processes as mental models, were their being temporary structures in WM that were momentarily

constructed and revised in a stepwise fashion through an active construction process and (2) their being schematic representations that capture different visuospatial aspects of the building space/form at different levels of detail at different moments of the visualization process. In this active construction process, the architects were first creating a very generic frame-like 3D representation of the building space/form in WM which captures the proportional distances of the space/form, the relative locations of the components in the 3D space, and possibly silhouette-like renderings of the components but not the detailed appearances in a structure similar to that of the spatial structure of the visualized space/form in SS or LS. Once they generated this model, they were encoding it into their LTMs as the main scheme of the visualized building space/form. Then, they were beginning to fit in more detailed representations of components to this generic model one at a time in a stepwise fashion by relating each component to the nearby components much like knitting a 3D mesh. While they were doing so, these architects' 3D SS or LS mental representations of the visualized building space/form were going under continuous change with regard to which of the building components and at which level of detail these components were rendered in them. In other words, the visual and spatial aspects of that building space/form rendered in these mental representations were continuously changing along the visualization process.

In this visualization process architects were concurrently making inferences about visibility of the components, i.e. which of the components they should be seeing and how these components would be appearing from their current location. In making these inferences they were plausibly calling upon their knowledge about how to identify the components that would fall into the visual field based on the section and plan views of a building and recalling and integrating information from the 2D views of the building. Thus, during their visualization processes, the architects were not only constructing a mental representation of the 3D building space/form by calling upon perception-based LTM information about the 3D appearances of the components but making inferences by

drawing upon LTM information other than the visual and spatial information attained from the 2D drawings of the buildings.

In this visualization process the mental representations that architects were creating exhibiting the characteristics of the perceptual mental models. They were iconic representations in that they were capturing the visuospatial aspects of the visualized building space/form by preserving a 3D spatial structure similar to that of a LS or SS 3D model of the visualized building space(s)/form. They had modal constituents in that they were embodying visual-perception based representations of the building components.

Considering the limitations of the WM capacity, I understand that these architects most likely were not maintaining all the added detailed representations of the components in their WM representations throughout their construction processes. Rather, they were continuously encoding these added detailed representations into their LTMs at some intervals of their visualization process. This way they were (1) offloading the previously added details from their WM, (2) mainly continuing to add detailed representations of the subsequent components into their generic frame-like models and (3) reaching at a complete LTM representation of the visualized building space/form. Thus, what these architects captured at different moments of their visualization processes was more like the general frame representation of the 3D building space involving detailed renderings of some but not all the components in that building space/form.

In the study session of the drawings of the buildings the architects were requested to visualize what they would be seeing if they were to be walking inside the various spaces of B1, and around the B2. They were informed that they would be asked to describe these visualizations of walking after the study session. They were also informed that after the study session they would be specified certain locations by the experimenter and would be asked to visualize what they would be seeing from those locations. Thus, in the study session of the drawings they did not know the locations from which they would need to visualize the buildings in the absence of the drawings after the study session, but

they knew that they would be asked to describe their visualizations of walking inside B1 and around B2. In this respect, they had a chance to visualize all the spaces on a self selected path, for instance and it was possible that they did so. This means that they could have generated and encoded the 3D LS or SS representations of the building spaces or exterior forms that they would encounter on a path. Yet, in all the tasks, the architects were observed to be constructing their mental representations of the visualized building space and form in a stepwise fashion regardless of the possible differences between some of these mental representations being previously constructed and encoded into LTM during the study process. Construction and reconstruction of the WM representations of the visualized building spaces in the same stepwise fashion makes a lot of sense when we think those that these architects when initially constructing their WM representations (1) had captured the detailed representations of some but not all the components of the visualized building space/form at once and (2) thereby the LTM correspondences of these representations of the visualized space/form were formed by encoding detailed representations of some of the components in that building space/form at a time. Overall, looking from these perspectives, I infer that what these architects experienced in their imagination during their visualization processes were not like the holistic visuospatial experience one would have when looking at an actual building space/form.

7.1.3 Further Issues

3D LS versus 3D SS Visualization of Buildings

Based on my analyses of the circumstances at which the architects switched from 3D LS to 3D SS and 3D SS to 3D LS visualization, I understand that 3D LS visualization is a less cognitively affordable form of visualization than 3D SS in that it puts greater demands on the cognitive capacities and processes than 3D SS visualization. I further understand that 3D LS visualization relies on some abilities and processes that are not

involved in 3D SS visualization and could be a less common skill than 3D SS among the architects.

2D SS Visualization & Imagining Walking in Building Environments

When carrying out the walking tasks, the LSV architects were intermittently switching to 2D SS visualization in the situations where they were about to change or in the process of changing their relative positions on the building's floor/site layout. I interpret that these architects were doing so because these intermittent switches to 2D visualization was helping these architects to keep track of their relative positions on the floor or site layout and the spaces or the building masses that they would encounter on their path, much like way the quick looks to a 2D map of a virtual environment supports one's navigation through the various spaces or areas of that virtual environment.

7.1.4 Implications of the Findings for Architectural Education and Practice

Based on the inferences made in this study, I understand that architects or students when they say they are mentally visualizing the buildings in 3D, in the various contexts where they are presented with 2D drawings of building, or while they are working out their design ideas with 2D sketches, can be doing so in one of the forms or by alternatively switching between them. They can visualize the building in 3D LS i.e. by imagining themselves situated within an actual size or almost the actual size building environment, or they can visualize the building in 3D SS i.e. by imagining a 3D SS model of the visualized portion of the building. In the mental representations they create in their 3D SS or LS visualization processes, these architects can capture the 3D layout of the building spaces or form, the relations of the various components in the building, the 3D shapes and approximate relative dimensions of the components and the overall space/form with a spatial structure that is similar to that of a 3D LS or SS model of the building.

However the way these architects capture these various visual and spatial aspects of the visualized building space/form in 3D SS or LS are not like the way they would be captured from a specific viewpoint in reality. Furthermore, their visuospatial experiences are not like the continuous holistic visuospatial experience that one would have when looking at a 3D SS or LS model of the building ; rather they are dynamic experiences where the visuospatial aspects of the building that are captured in detail continuously changes. I also understand that when architects say they are imagining themselves walking inside or outside a building, they are plausibly doing so mainly by imagining themselves at sequences of locations on a path in a motionless manner. Thus what they experience during their visualizations of walking is not like the continuous visuospatial experience that one would have while walking; rather it is much like a sequences of the visuospatial experiences they have when imagining a building space/form in 3D LS or SS i.e. sequences of dynamic experiences where the visuospatial aspects of each of the imagined building spaces or different sides of the building continuously changes.

These mean that such visualization practices, although architects can capture various visuospatial aspects of the building space/form, could not be relied on in making inferences that necessitates capturing these visuospatial aspects from a certain viewpoint in a holistic fashion. For instance, they cannot be relied on apprehending how the cascading frames of the views in a design would be visually apprehended by the occupants when looking from a certain location inside the space or how the building would appear from a distance when one would be approaching to it. Accordingly, I understand that 3D mental visualization practices can be counted on for conveying the 3D visuospatial aspects of the buildings through 2D drawings or for exploring such aspects of a design idea while generating 2D sketches; yet they cannot be counted on to precisely convey the appearance of a building space/form or a 3D SS model of it from a certain viewpoint or the visuospatial experience one would have when looking at that building space/form.

Within all these circumstances, when looked from the perspective of how quickly architects can a 3D mental representation of the building in such visualization practices, it seems that 3D mental visualization practices can be very efficient means for architects to develop a 3D understanding about a building design presented through 2D drawings, and for exploring various aspects of the design ideas individually or in collaborative design practices through 2D sketches. Yet, it seems not every architect can visualize the buildings in 3D LS based on its 2D drawing to the extent that to the extent that some architects might be solely carrying out their 3D mental visualization practices in 3D SS.

Architectural design implicates visualization of the design ideas in both forms not only because each form of visualization supports thinking of certain aspects of the design in 3D more efficiently than the other but also because in some cases the aspects of the design that are focused on can only be examined and thought of in one of these forms. For instance, examining and reasoning about the compositional aspects of large scale systems in the buildings such as the buildings' structural system, the buildings' exterior mass or roof structure, organization of multiple spaces at various levels, and etc. implicates capturing the overall configuration of the large scale system at once. On the contrary, thinking about the aspects of the design from the perspective of the occupants - in the way the occupants will experience and interact with them such as layout of the furniture, how the size of a space will be apprehended relative to the body implicates capturing the building space(s) or form in its actual size as would be apprehended from within. Under these circumstances, some architects' not being able to visualize in 3D LS could mean that they won't be able to use 3D mental visualization as a medium for exploring certain aspects of a design that can be better thought of from an inside perspective which in turn could lead to drawbacks in their conceptions of certain aspects of their design ideas. While an architect can handle limitations in 3D LS visualization skills during her own design process by relying on external visualization tools, she can not do so in the situations where she is presented with 2D drawings of a building such as

in the context of a design studio, or a design meeting in the office. Thus, in case an architect presents 2D drawings of a building to another architects with the intention convey some 3D aspects of a building space as would be apprehended from within, the receiving architects' not being able to visualize in 3D LS would mean that these two architects would not have the same apprehension of the space during that communication.

When I consider that architects during their thinking processes not only conceive of the buildings in 3D LS from within but also in the form of a 3D small scale model in conjunction with the fact that people generally apprehend building spaces from within during their daily lives, it seems that 3D SS visualization can mainly be an architectural form of visualization. This form of visualization begins to come into existence during architectural design education as students begin to construct and think with 3D SS models of their design ideas. Based on my investigation, I understand that 3D LS visualization skills rely on some abilities and capacities that are not involved in 3D SS visualization processes. When I think of this along with those that (1) 3D LS visualization skill was found to be less common among the architects who participated in this study, (2) 3D SS visualization could be an architectural form of visualization and (3) people generally apprehend the building spaces from within, I come to the conclusions that (1) both 3D SS and LS visualization skills could be becoming heightened in the context of architectural education but (2) their development could be fostered through different kinds of training (3) and the training that supports development of 3D LS visualization skills could be less commonly provided in the architectural schools than those that support development of 3D SS visualization skills. Considering the affordances of both forms of visualization, I suggest that we should explore such differences in 3D LS and SS visualization skills by further studies to be able to understand the sources of individual differences in such skills and to devise educational interventions through which we can support development of these skills.

7.2 3D Mental Visualization Capabilities

The rest of the research questions in this study were aimed at investigating the 3D mental visualization capabilities of architects from a number of perspectives. These questions were:

- (2) Can every architect carry out these 3D mental visualization practices; might there be individual differences among architects in their 3D mental visualization performances?
- (3) Might 3D mental visualization of buildings be only an architectural skill?
 - a. Can non-architects, who can read 2D architectural drawings, visualize a building in 3D based on its 2D drawings?
 - b. Can they do so at the same levels of performance at those that architects can?
- (4) Might performance in 3D mental visualization be related to/predicted by SVA?

In the following, I will first summarize findings that were reached at in this study on the basis of each of these research questions and discuss their implications for architectural education and practice.

7.2.1 Q-2: Individual Differences among Architects

In this study all the architecture participants were found to be able to mentally visualize the given building designs in 3D based on their 2D drawings; however there were variances among their 3D mental visualization performances within each of the visualization tasks with respect to their being able to completely and accurately capture the 3D building information in their mental visualizations. This implies that every architect, and supposedly architecture student¹⁸, can plausibly mentally visualize a

¹⁸ The architecture participants in this study were all graduate students of architecture who either had a professional degree in architecture or had a Bachelor of Science degree in Architecture and were studying towards gaining their professional degrees. The differences among these architecture participants' 3D mental visualization performances could be an outcome of various factors that might have come into play before, during or after their graduation from university. Yet, it is very unlikely that they were an outcome

building space/form in 3D based on its 2D drawings. However, the architects and students differ in their levels of 3D mental visualization performances.

In this study two factors were examined to investigate whether they can account for the differences of 3D mental visualization performances among architecture participants. These were the years of work experience that architects had and the years passed since they carried out a design project. No relationship was found between these factors and the 3D mental visualization performances. These results imply that work experience might not be playing a role in improvement of 3D mental visualization skills; these skills might not be declining as a result of the years passed since the last design activity. Taken together these further imply that in case these skills become heightened in architects, they could be becoming heightened more during education than in the context of professional practice. If so, this would mean that educational interventions becomes of critical importance for supporting improvement of these skills.

Such individual differences in 3D mental visualization skills could have various consequences for architects' education and practice. This could mean that students when presented with or come across with 2D drawings of a building design in the various educational contexts, such as in the publications, in various courses, or in the design studio reviews of the student projects or case studies, could be apprehending the 3D building information at different levels of completeness and/or accuracy or could be having difficulty doing so. As a result differences might be occurring in the extent and form of the knowledge that the students are supposed to build up based on the presented class or design studio material and thereby in the way they can transfer and apply this knowledge in their design processes. Such individual differences in 3D mental visualization skills could also mean differences in the students' and architects' design

of factors that come into being only after the graduation and it is very likely there are individual differences in 3D mental visualization performances among architecture students.

processes and design thinking. In their design processes, individuals with low level 3D mental visualization skills could be relying more on external visualization tools or 3D physical models for examining and exploring the 3D aspects of design ideas. Accordingly, depending on the functionality of computer tools or the kind of physical models being built, they could be spending most of their times and efforts in modeling their design ideas and less of their times on exploring alternative design ideas. Furthermore, the used tools could be implicating certain modeling methods and thereby limiting the ideas that they could model and explore in their design processes. Use of such tools could also be requiring certain skills which might be more limited in some students and architects than others leading to drawbacks in their design. Such individual differences in 3D mental visualization skills could also mean lack of communication and thereby misconception of the aspects of design that are being discussed between the student and the instructors or in a design team where the design ideas are communicated extensively through 2D sketches.

When we think of these consequences, it becomes of major importance to begin to understand what the sources of such individual differences in these skills might be; whether they could be an outcome of the differences in the basic abilities that underlie these skills and/or domain specific training and practices; whether we can predict these individual differences prior to education or improve them during education among others.

7.2.2 Q-3: Architects versus Non-Architects

In the analyses of the participants' 3D mental visualization performances, it was seen that mechanical engineering participants were able to visualize the buildings based on their 2D drawings; yet, their performances were found to be significantly lower than that of the architecture participants. When we consider this finding in the light of the information that all the architects and mechanical engineering participants in this study reported to be carrying out 3D mental visualization practices during their design activities

this finding indicates that the 3D mental visualization of buildings involve some abilities that are not involved in the kinds of mental visualization practices that the mechanical engineering participants carry out during their design activities. This implies that 3D mental visualization is mostly an architectural skill in that it relies on certain abilities that become heightened in architects possibly more during education than during professional practice.

7.2.3 Q-4: 3D Mental Visualization & SVA

In this study no relationship was found between the performances of participants in 3D mental visualization tasks and SVAs. This indicates that SVA, unlike generally believed, is not a crucial ability for the kinds of 3D mental visualization tasks investigated in this study and cannot predict performance on these tasks. This result further indicates that spatial cognition in architectural design cannot be studied and understood simply on the basis of the existing spatial ability constructs which are identified by paper and pencil tests of spatial ability. This could be one of the reasons for why a conclusive finding could not be reached in the previous studies which investigated the relationships between spatial abilities of the architecture students as measured by the paper pencil tests and their design and/or academic performances (Ho 2006; Yukhina 2007).

7.3 Implications of the Findings for Cognitive Science Research

7.3.1 The Nature of Mental Representations That Capture Visual and Spatial

Aspects of the World

So far our understanding about the nature of the temporary mental representations that capture the visual and spatial aspects of the world mainly came from two different frameworks of research. One of these has been the visual mental imagery framework while the other has been various lines of research in mental modeling framework which

looked at the nature of the mental models that underlie reasoning or comprehension processes which implicates a mental model capturing both visual and spatial aspects of the world. In mental modeling framework mental models and images have been treated separately; mental models have either explicitly characterized to be different from visual mental images or have been defined to somehow accompany mental models. Johnson-Laird (1983), in his theory of mental models defined mental models as structural analogues of an imaginary or real world situation, event or process which captures the spatial, temporal and causal relationships such as spatial relations between entities in a situation or casual relation between events. In his account (Johnson-Laird 1989), Johnson-Laird characterized mental images as 2D projections of 3D mental models from a certain viewpoint rather than a different type of mental representations in that they are projected from visualizable aspects of the underlying mental models. Bryant and Twersky et al. (2001) based on a series of research studies carried by their research group suggested that spatial mental models that people construct reflect conceptions of the spaces rather than perceptions of them and thereby are not like mental images. Nersessian (2002) underlined that perceptual mental models are not like images; they are schematic and abstract rather than vivid like mental images but they can be accompanied by images. Schwartz and Black (1996b) in their definition of the depictive mental models, implied parallels between mental images and the depictive models both being perception-based representations and both being operated on by analog processes. Hegarty (2004), based on her work and her review of the mental animation research suggested that mental models of the physical systems that people create can involve analog imagery and can be accompanied by mental images.

So far, the characteristics of the mental images and the mental models that capture visual and spatial aspects of the world, except for Nersessian (2008), have mostly been investigated and defined in the context of processes and tasks which implicate creating a mental representation of a 2D or 3D small scale spatial configuration. Here by small

scale, I mean configurations which can be apprehended within the limits of one's field of vision from a single vantage point such as 3D objects composed of cubes, basic shapes of letters, or a small scale diagram of a pair of gears. By large scale configurations, I mean configurations such as a gallery space of a building or the exterior mass of a building, which cannot be apprehended at once within the limits of one's field of vision and thereby whose apprehension requires alteration of the sight line, turning around, or locomotion of the body. The research in mental modeling, which has focused on the nature of mental representations of large scale 3D spatial configurations, has mainly investigated these mental representations in the context of tasks which implicate capturing spatial aspects, but not the visual aspects of the world. Overall, the insights we have gained on the nature of mental representations that capture both visual and spatial aspects of the world has been mostly limited to mental representations of small scale spatial configurations and our understanding about the nature of mental representations of large scale 3D spatial configurations has been limited to the representations that capture only the spatial aspects of the large configurations.

In this study, the visualization tasks that architects carried out implicated creation of mental representations that would capture both the visual and spatial aspects of a building space(s)/form. Based on the analyses conducted in this study, it is interpreted that the architects in the mental representations they created indeed captured both visual and spatial aspects of the visualized building space(s)/form in one of the two different ways. They captured them either with a spatial structure similar to that of the a visualized building space(s)/form in actual size or with a spatial structure similar to that of a 3D small scale model of the visualized space(s)/form. In this regard, this study has provided some new insights on the characteristics of mental representations which capture both visual and spatial aspects of large scale configurations as well as small scale configurations. When I consider the characteristics of the mental representations that the architects constructed in their visualization processes in this study in conjunction with

characteristics of the mental representations that people have been found to create during tasks or processes that implicate capturing visual and/or spatial information in the previous studies, I come to the following conclusions:

- It were the differences in the aspects of the world to be captured in the mental representations and the spatial dimensionality and scale in which these aspects need to be captured which resulted in the main differences outlined between mental models and mental images and, in turn, different conceptions of mental images and mental models. These differences were that (1) mental images are bound to a certain viewpoint but not mental models, (2) mental models of spaces reflect conceptions of the space rather than perceptions of the space and (3) mental models are schematic representations while mental images are ‘picture like’ vivid representations.
- The mental representations which capture 2D or 3D small scale entities’ visual and spatial aspects, such as in the studies of mental imagery and some studies in mental modeling research, and visuospatial mental representations that architects constructed during 3D SS and LS visualization process of large scale building environments in this study should not be conceptualized as different representations.

In order to explicate these conclusions, I will first discuss what would be the implications of a mental representation capturing only certain spatial but not visual aspects of the world versus a mental representation capturing both spatial and visual aspects of the world. Then I will discuss what would be the implications of a mental representation capturing the visual and spatial aspects of a spatial configuration or entity with a spatial structure similar to that of the object or configuration which is a 2D or 3D small scale or 3D large scale object or configuration. Following these discussions, I will turn to previous research in mental imagery and research in mental modeling where the investigated mental representation pertained to a task that implicated capturing both

visual and spatial or only spatial aspects of the world. I will outline the characteristics of the mental representations defined in these research studies with a focus on the tasks or processes in the context of which these mental representations have been investigated, the dimensionality and scale of space in which the visual and spatial or spatial aspects of the world are implicated to be captured in these mental representations. Then I will revisit and discuss the differences that have been outlined between mental models and mental images in the light of characteristics of the architects' mental representations of the visualized building space/form that are inferred in this study. On the basis of this discussion, I will suggest an integral perspective that all these classes of mental representations, which capture visuospatial aspects of the world, are indeed different instantiations of a common representational system, which can be characterized as perceptual mental models, rather than different representations.

Visual and/or Spatial?

In the last few decades there have been substantial neuropsychological evidence indicating that human cognitive system processes visual information, the what system, and spatial information, the where system, separately (e.g. Haxby, Grady et al. 1991; Kosslyn and Koenig 1992). These findings also extend to imagery (Levine, Farah et al. 1985; Farah, Hammond et al. 1988; Kosslyn, Ganis et al. 2001), individual differences in visualization styles (Kozhevnikov, Hegarty et al. 2002; Kozhevnikov, Kosslyn et al. 2005; Chabris, Jerde et al. 2006), and individual differences in each spatial and visual imagery abilities (Blajenkova, Kozhevnikov et al. 2006). The 'what' system processes visual properties of the objects such as their shape, color and size and the 'where' system processes the localizations of these objects in space and the spatial relations between parts of an object or among various objects in a configuration. Thus visual imagery refers to representation of visual appearance of an object, its shape, form, color, brightness while spatial imagery refers to representation of the spatial relations and locations of

parts of an object or objects in space. Thus, visual images are detailed, vivid representations of object properties, while spatial images are more schematic representations in nature (Blajenkova, Kozhevnikov et al. 2006).

When encoding a multipart object, we can consider ‘where’ system to locate parts of the object in space and their spatial relations and the ‘what’ system to encode the parts’ visual properties such as shape, dimensions, color etc. Yet, as Newcombe and Huttenlocher (2000) underline, the cut between the ‘where’ and the ‘what’ system is an ambiguous one in that we don’t know where ‘where’ system stops and ‘what’ system begins. For instance, when encoding a multipart object, one can further decompose each object part, such as a rectangle, into its constituents, such as the outlining lines. Accordingly, the ‘where system’ can be locating the units of lines that make up each object part, their spatial locations and relations between them and what system can be encoding the dimension of each line, its color etc. As another alternative, this multipart object can be encoded by the ‘what’ system as a holistic image much like the way one would encode the appearance of a person’s face. Looking from this perspective, I think that the distinction between the spatial and visual mental representations, or images, is not a clear cut one either because the spatial representation of a multipart object eventually embodies the shape and dimensions of the object and its parts i.e. some visual aspects of it. For instance, when processing a spatial configuration composed of lines drawn in a pattern spatially i.e. encoding the pattern as units of lines in space and the connections between them, you are in a sense also capturing the appearance of a multipart pattern, its overall form and dimensions in a piecemeal fashion. Thus you are capturing the shape of a configuration, that would be considered visual, but in a piecemeal and schematic fashion rather than capturing it in a holistic and vivid fashion. In this discussion, I will use three terms to differentiate the visual and spatial aspects of the world captured in the mental representations. I will use visual to refer to detailed vivid visual representations of parts or objects with their shapes, colors, brightness and

etc. I will use the term ‘visuospatial’ to refer to the representations (1) which are more schematic in nature than visual and (2) which embody visual representations of the units of shapes that make up the object such as lines, circles in a pattern, their sizes and dimensions and their spatial relations and locations in the object space and thereby which naturally captures the overall shape and dimensions of that object or pattern. Thus these representations both involve shapes -as a visual aspect, and their composition as spatial, and the shape of an overall object or the space as visual. I will use term spatial to refer to the representations which do not involve any visual aspects such as a representation of a spatial configuration of objects where the objects are represented with amodal tokens.

The visual and visuospatial representations will naturally be iconic representations as they would have a spatial structure similar to that of the represented. By spatial structure I mean spatial arrangement of parts in an object or objects in a space which captures spatial locations and spatial relations between the parts of the object or the objects. Thus these representations, being iconic, would implicate goodness of fit between the representing and the represented world. The spatial representations can also be iconic, in case the spatial relations between the amodal constituents in the representation are analog relations such as ‘T’, a token of table and ‘C’, a token of couch, are spatially related and represented as one being on the right of the other in space instead of propositionally represented propositionally such as table is on the right of the couch.

2D or 3D Small or Large Scale Visuospatial Configurations

In this discussion, I defined small scale as the objects of configurations that can be apprehended from a single viewpoint. This means that in their perception one does not need to alter one’s viewpoint of the object or configuration.

In case of 2D small scale configurations or figures, one can apprehend the overall configuration or the figure from a single viewpoint. What this further could mean is that if we can perceive a 2D flat object at once from a single viewpoint, then we can construct

a viewpoint specific representation of an object. This has been one of the characteristics which have been attributed to visual mental images but not mental models.

In case of 3D small scale objects or configurations, one can apprehend all the visible parts of the configuration or the object from a single vantage point in a sense capture a perspective view of the 3D object yet the invisible parts remains hidden and need to be inferred for a complete representation of the 3D composition of the object or the configuration. In this case, if one carries out a task that would demand capturing the 3D visuospatial structure of the object while looking at it, for instance, if one were to imagine how the object would appear when rotated, then one would need to fill in the gaps of the 3D visuospatial representation of the object and capture the objects' overall 3D structure. In such a case, the mental representation of the 3D object would plausibly not be bound to the specific perspective, in which that object was viewed, because the person is aiming to capture the overall spatial structure of the object. Yet, if one is requested to make an inference from memory relating to the visible parts, such as one of the part's spatial relation to the others on the visible surfaces of objects, one would not need to construct a mental representation where she would capture the 3D visuospatial structure of the object; rather she would plausibly construct a mental representation of the object which captures the appearance of the object from the viewpoint that it was seen previously. In such a case, the mental representation of the object would be bound to a specific viewpoint.

What would happen in large scale spatial configurations? As I previously defined by large scale I mean the 3D spatial configurations whose visible parts (i.e. parts for instance one would be facing), cannot be all apprehended at a glance from a single vantage point within the limits of the field of vision, and whose apprehension requires change of the sightline of the viewpoint, such as focusing the eye to different parts, turning the head or locomotion. For instance, such large scale configurations include the building's exterior mass, one side of an interior space of building, the overall

surroundings in a space or multilevel space and etc. In such 3D large scale configurations, one would need to alter her sightline or viewpoint location to apprehend the different portions of the space thus they would be registering the appearance of the surroundings from multiple viewpoints much like capturing a panoramic view of the space from a single location by turning around or capturing sequences of views by walking. Then, on what basis would one structure her mental representation of the appearance of the surroundings in a space in case she needs to recapture it? Would it be like sequences of perspectives that would eventually have overlapping contents in terms of the parts of the space captured in each or would it be different representation associated with the 3D structure of the space itself rather than how the space is perceived from different viewpoints. Based on the understanding attained in this study, I propose that it would be the latter. Yet in case the person is taken to a building space and asked to capture a specific perspective from a specific viewpoint and then given this intention asked to recap this perspective from memory to carry out a particular inference task, then I propose this person would be able to construct a viewpoint specific perspective of that space.

Mental imagery

Mental images are analogous to percepts in they embody both visual and spatial information and they can be examined, further interpreted, and operated on to extract novel information (Kosslyn 1994). So far extensive research has been conducted to investigate the information available in mental images and the operations carried out on images such as scanning, zooming, and reconfiguring parts (e.g. Kosslyn, Ball et al. 1978; Finke, Pinker et al. 1989; Kosslyn and Denis 1999) and spatial mental transformations, such as mentally rotation of images of objects (Shepard and Metzler 1971). These studies provide extensive amount of evidence in support of the view that mental images are functional analogues of percepts and the operations, such as scanning,

carried on images are functionally analogous to those on percepts in that they involve the same processes and mechanisms that underlie perception. Likewise, spatial mental transformations carried out on images of objects are functionally analogous to transformations carried out on actual objects in space. In the mental imagery framework, the evidence on the resemblance between images and percepts, both as representations and in terms of the operations conducted on them, has mainly been derived from and interpreted through processes which involve construction of an image of small scale stimuli either from direct perception or from memory. For instance, in the processes where the mental image is constructed from direct stimuli, the stimuli have been 2D or 3D projection views of objects or configurations in small scale such as such as a map (Kosslyn and Denis 1999) or a configuration of 3D rectangular blocks (Shepard and Metzler 1971). In the processes where a mental image is constructed from memory such as in creation of novel objects by reconfiguring parts (Finke and Slayton 1988; Finke, Pinker et al. 1989), or mentally drawing a shape (Kosslyn 1994), the spatial configurations that are imagined have also been 2D small scale spatial configurations such as configuring D and J into an umbrella by rotating the D 90 degrees and attaching J in the middle, or imagining the resulting spatial configuration such as by going 1 inch to east, then north, then west, and defining the overall pattern that is drawn. In all the research studies where images have been investigated and interpreted to be functional analogues of percepts and the operations on them to be functionally analogous to that on percepts, the processes in which these investigations were made have been the ones which would implicate spatial images rather than visual images i.e. vivid holistic representation of the presented or described stimuli. In the context of the three types of representations that I presented before, I would define these processes through which mental images were investigated as implicating a visuospatial representation that would capture the spatial structure of the presented or described figure and the shapes of the parts of the figure or the configuration.

Mental Models

In mental modeling framework there have been mainly three lines of research which looked at the nature of the mental models that underlie reasoning or comprehension processes that implicates a mental model capturing both spatial and visual aspects of the world. The first line of research is the mental animation research that investigated the characteristics of the mental models that people construct to simulate the motion of physical systems, such as a system of pulleys or a set of gears (Hegarty 1992; Schwartz and Black 1996b). In these studies people are provided with a 2D diagram of the initial setup of the gear or pulley system and asked to infer whether the marks on each of gears will meet if the gears are rotated or in which direction the pulley will rotate when the rope is pulled. In both studies people are found to mentally simulate the behavior of the physical systems to make the inferences¹⁹. Schwartz and Black (1996b) inferred that the participants in carrying out this task constructed depictive representations of the gear system and used analog imagery in simulating the behavior of the gear system. Here the ‘depictive’ can be interpreted as an iconic spatial representation embodying both visual and spatial aspects of the represented by preserving the constraints inherent to it. Hegarty (1992) characterized the mental representations of the pulley systems as being simulated in a piecemeal fashion, link by link (one pulley at a time), and simulation of each link to involve analog imagery as also observed by Schwartz and Black. Hegarty characterized the underlying mental representation as spatial representations. She did not underline involvement of visual information in the mental representations; though Hegarty (2004) later suggested that these simulations can be accompanied by the conscious experience of visual mental imagery. I interpret these mental representations of each link of the pulley system as iconic visuospatial representations in that by preserving the spatial structure of

¹⁹ Schwartz and Black found that people who do not have any knowledge about the behavior of systems carry out these tasks by analog imagery; he also reported two different strategies, which will not be outlined here.

the configuration of pulley system they would be embodying the shapes and sizes of the pulley.

In the second line of research, Cooper and her colleagues (as reviewed in Cooper 1989) investigated the structure of the mental models of the 3D objects that people construct based on their 2D drawings. In one study, first year mechanical engineering students were given compatibility tasks where they were requested to look at two projection drawings of an abstract object and provided two other views to select which of these views would be a third view of this object. After students carried out these tasks, they were then given a surprise recognition task. In this task the students were presented isometric views of objects some of which corresponded to the objects that were previously presented in the compatibility task, and were asked if they had recognized any of these isometric views from the previous task. Based on the analyses of the accuracies and latencies, Cooper interpreted that these students, when carrying out the compatibility tasks, constructed object like mental models of the presented abstract objects in that their mental models contained structural information similar to that would be viewed in an isometric projection. In a follow up study, researchers prepared 4 isometric views to present as a surprise recognition task after each problem in the orthographic compatibility test, in these isometric views 3 were distracters and 1 was the view of the presented object. These matching views were sharing three, two, one and zero common view with the presented sides of the object in the orthographic drawing. Researchers' on the analyses of the accuracy, and latency data, determined that these mental representations of 3D objects are neither strictly viewer centered ($1\frac{1}{2}$) nor object centered (fully in 3D) but something in between.

The third line of research in which the examined reasoning practices implicated capturing visual and spatial information was the research on mental modeling practices in scientific reasoning processes, such as visual modeling, analogical modeling and thought experimenting (Nersessian 2008). Nersessian in her analyses focused on complex

reasoning processes in that they involve creation and manipulation of series of mental models and lead to creation of new concepts, either novel to the field such as Maxwell's concept of electromagnetic field or to the individual such as one's creation of the concept of a spring when solving a problem about how much the spring bends. In Nersessian's analyses the kinds of mental models that underlie these practices are characterized as perceptual mental models, which, as I outlined earlier, are iconic modal representations of a situation, event, or process and which can be simulated in dynamic cases. Processes of construction, manipulation and revision of perceptual mental models can make use of information from various sources, both internal and external, and in various formats including linguistic, formulaic, imagistic (all perceptual modalities) such as equations, diagrams, picture, maps, physical models and various auditory and kinesthetic experiences. It follows from this account that these perceptual mental models can capture 2D or 3D visual and spatial as well as other information in representing small or large scale spatial systems.

Up to this point, I have outlined the research where the mental representations involved visuospatial aspects of the world. In concluding this discussion, I first want to give a brief overview of a series of research studies which investigated the nature of the mental models, namely the spatial mental models that people construct to infer the spatial relations among the objects located within large scale spatial configurations.

One line of research investigated the nature of mental models, namely spatial mental models that that people construct to infer the spatial relations among the objects located within large scale spatial configurations. In two studies, people were given narratives of spatial configuration of arrays which describe the relative locations of objects with second and third person perspectives, such as the participant is standing and the 'character' is standing (Franklin and Tversky 1990; Bryant, Tversky et al. 1992). In these spatial configurations the character is surrounded by objects located at 6 different directions of the body, the head, feet, front, back, left and right. After the participants

read the narratives they were prompted with directions by the computer. The directions were indicated by reference to an object in the scene such as you (the participant) are facing ‘the object’ and asked what would be the object in another direction. In the analysis of the times it took participants to report the objects in relative directions, the researchers found that the response times to be matching to the spatial framework pattern. In the spatial framework theory developed from this research, people construct a mental spatial framework based on the extensions of the three body axes, the head-feet, front-back, and left-right and associate the objects to this mental spatial framework. Time to access objects depends on the alignments of the body axes with the gravity axes of the world. For instance for the upright observer the head-feet axis is the most accessible then the front and behind and the left right is the least accessible. In the follow-up studies (Bryant and Tversky 1999; Bryant, Tversky et al. 2001), researchers found the same spatial framework pattern where the participants were asked to report the directions of the objects from memory after they studied a large scale 3D spatial configuration by looking at a depiction of a model of a 3D scene (which is like a perspective drawing) where a doll is surrounded by objects at the six sides of the body, and where they had learned the 3D large scale spatial configuration from experience. On the contrary, when the participants were probed to report the directions of the surrounding objects in a real setting, their response times correlated with the ‘physical transformation model.’ According to this model, the people would respond the fastest for the front, and next equally fast to right, left, head and feet, since these all require a turn of 90 degrees from front, and slowest to the back, since this requires a 180 degree turn of the body. Based on these outcomes researchers have proposed that spatial mental models are structured around the core representation of one’s body and gravity, and they represent people’s conceptions of space around the body rather than perceptions of it. Within these studies, as underlined by Bryant and Tversky et al. (2001), the spatial mental models have been considered as representations of objects and spatial relations between them where the spatial relations

within and between objects need not be analog and the objects might be represented incompletely even one dimensionally as markers.

Mental Imagery & Mental Models: An Integral Perspective

In Table 18, I summarize the collective characteristics of the mental models and images that have been outlined in the above lines of research and the characteristics of the architects' mental representations of the buildings as interpreted in their LS and SS visualizations of the building space(s)/form in this study. In this table, I outline the characteristics of the mental representations as inferred from these various research studies, in association with the tasks or processes in the context of which they were created, the dimensionality and spatial scale of the situation or entity whose aspects need to be captured in these mental representations and the aspects to be captured based on the demands of the carried task or process, and the sources which informed the creation of these mental representations.

Table 18 Characteristics of mental models and mental images and the mental representations architects create during their visualization processes

Source (s) of information : Depictions or descriptions of 2D (plane) figures of small scale objects or configurations			
Line of research	Tasks/processes	Aspects to be captured	Characteristics (& outlined differences of models from images)
Operations carried out on visual mental images	Scaling, scanning, rotating, translating, reconfiguration of parts of a 2D image	2D Visuospatial aspects of a 2D figure or configuration	<ul style="list-style-type: none"> - Functional analogues of percepts that capture the visual representation of the shapes or its parts and the spatial relations and relative locations of these parts in 2D; thus iconic, visuospatial representations that preserve the 2D spatial structure of the represented figure - Analog processes
Mental animation research	Inferring the motion of physical systems	2D visuospatial aspects of the physical systems	<ul style="list-style-type: none"> - iconic visuospatial representations that capture the 2D spatial structure of the configuration ; - analog processes in rotation of gears and movements of a pulley at each link
Source (s) of information: 3D projection views of small scale 3D objects, multiple 2D views of a small scale 3D object			
Line of research	Tasks/processes	Aspects to be captured	Characteristics (& outlined differences of models from images)
Spatial transformations of images	Mental spatial rotation of images of 3D objects	3D visuospatial aspects	<ul style="list-style-type: none"> - mental rotation of the imagined 3D object being analogous to rotation of an actual object in 3D space - iconic visuospatial representations that preserve the 3D spatial structure of the object
Structure of Mental models of 3D objects	<p>Orthographic compatibility, recognition of a missing projection view of an object based on its given 2D projection views</p> <p>Identifying the isometric view of the object from the given set of isometric views</p>	3D visuospatial aspects as would be captured in an isometric projection view of the object	<ul style="list-style-type: none"> - 3D mental models of objects constructed from their 2D projection have a structure similar to that displayed in an isometric projection, they were 'object like'; thus they were visuospatial representations - these mental representations of 3D objects are neither strictly viewer centered (1 ½) nor object centered (fully in 3D) something in between

Table 18 continued

Source (s) of information : Multiple sources of information, both external and internal, depictive or descriptive related to 2D or 3D, small scale or large scale configurations			
Line of research	Tasks/processes	Aspects to be captured	Characteristics (& outlined differences of models from images)
Perceptual mental models in scientific reasoning	Solving scientific problems, creating new concepts by analogical modeling, mental simulation and visual modeling	2D or 3D visual and spatial as well as other aspects which can be mentally simulated	<ul style="list-style-type: none"> - iconic representations of situations, entities, processes or events which embody perception-based representations - can be manipulated, revised or simulated by preserving the constraints inherent to the represented (mental models are not like mental images, though they can be accompanied by images which are conceptualized as vivid visual representations)
Source (s) of information : Narratives of the spatial locations of objects in 3D large scale spaces Memory of spatial locations of objects in 3D large scale spaces that are learnt by direct experience 3D projection view of a large scale space where objects are located at different sides of a doll			
Line of research	Tasks/processes	Aspects to be captured	Characteristics (& outlined differences of models from images)
Spatial mental models of relations between objects	Inferring the relative directions of the objects in the large scale space with respect to the body	Spatial relations between the objects in a large scale spatial configuration and the self	<ul style="list-style-type: none"> - can be iconic or categorical representations - mental representations of the spatial relations between objects are centered around the axes of one's own body (they represent conceptions of space not the perceptions of them like images)
Source (s) of information : 2D small scale projection drawings of 3D large scale configurations, the buildings			
Line of research	Tasks/processes	Aspects to be captured	Characteristics (& outlined differences of models from images)
Perceptual mental models of the building space(s)/form	Mentally visualizing the 3D building space(s)/form as would be seen by the eye from a given location i.e. from a particular viewpoint or while walking i.e. from sequences of changing viewpoints	3D Visual and spatial aspects of the building space/form as would be captured from a particular viewpoint or sequences of different viewpoints	<ul style="list-style-type: none"> - iconic visuospatial representations that have a 3D spatial structure similar to that of 3D large scale (approximately an actual size) or a 3D small scale model of the visualized space(s)/form - capture approximate proportional distances among the components in 3D space/form and embody 3D visual representations of the components including their shapes and dimensions as well as the shapes and dimensions of the containing space/form - capture the visuospatial aspects of building space(s)/form not ;like the way they would be captured from a particular viewpoint

When we look at the interpreted characteristics of mental representations in the previous research along with the aspects to be captured in these representations, three patterns emerge in the aspects of the entities or configurations implicated to be captured in the mental representation and the characteristics of the mental representations that are interpreted.

Pattern 1

In research where the mental representations need to capture both visuospatial aspects of a 2D configuration or entity, as in the cases of mental imagery research and research in mental simulation, the findings suggest that these representations are visuospatial in that they preserve the 2D spatial structure of the stimuli and embody the visual representation of the shapes. Furthermore, the findings suggest that the operations carried out on these mental representations in mental imagery and mental animation of a pair of gears or each link in the pulley system involve analog processes.

Pattern 2

In imagery research, where the mental representation needs to capture visuospatial structure of a 3D object, we see that the findings suggest that these representations are visuospatial representations that preserve the 3D spatial structure of the object. Likewise in research where the mental representation need to capture the visuospatial aspects of a 3D small scale object as would be captured in an isometric projection view of the object, the findings suggest that the mental representations are visuospatial representations that capture the 3D structure of the object with a structure similar to that displayed in an isometric projection; they were ‘object like’. Here we also see that the representations that capture the visuospatial aspects of a 3D object in a structure similar to the isometric projection view of an object, were neither viewpoint specific nor viewpoint independent.

In this study, some architects in their mental visualization processes imagined the building space(s)/form in 3D SS much like a 3D SS model of that part of the building or the building. It was inferred that these architects' mental representations captured the visuospatial aspects of the visualized space(s)/form with a spatial structure similar to that of 3D small scale model of that space/form. It was also inferred that these mental representations did not capture the visuospatial aspects of a 3D small scale model of the building from a certain viewpoint.

Previously, I suggested that we can apprehend only the visible parts of 3D small scale objects from a single viewpoint. I further suggested that depending on the inferences to be made, one's mental representation of a 3D SS object after perception could be viewpoint specific or not. In case one needs to capture the overall 3D visuospatial structure after perceiving a 3D small scale object from a particular viewpoint, this would mean the person would construct such a visuospatial representation by integrating the visuospatial aspects of the other side of the object by inferring them, so the resulting mental representation would not be viewpoint specific. In case one needs to make an inference based on the apprehended portion of a SS object, then I suggested that her mental representation of that 3D small scale object could be viewpoint specific. When looked from this perspective, Cooper's (1989) interpretations on the isometric like representations of the 3D objects being neither viewpoint specific nor viewpoint free makes a lot of sense; here the task demands capturing an isometric view which is a 3D projection view. Isometric projection is not a view from single viewpoint and not a viewpoint independent view either. Likewise, the inference that these architects' mental representations of the 3D SS model of the building are not viewpoint specific makes a lot of sense. The tasks in this study normally demanded imagination of the 3D appearance of building space(s)/form within in its actual size, and in their study session the architects were informed that they would be asked to visualize the building from a spontaneously given viewpoint after the study session. In a 3D SS visualization strategy this would, as

inferred in these architects' mental representations, implicate capturing the visuospatial aspects of the visualized building space(s)/form with a 3D spatial structure similar to that of a 3D SS model of the building. Accordingly, capturing the visuospatial aspects of an object in 3D would implicate a non-viewpoint specific representation of the 3D SS because one can only apprehend one portion of a 3D SS object from a single viewpoint.

Pattern 3

In research where the mental representations need to capture the relative spatial directions of the objects in 3D large scale space with respect to self, we see that the findings suggest that in the mental representation the relative spatial directions of the objects in a 3D large scale space around the body were captured in association with the structure of the central axes of the body and these relative directional relations could be analogous or categorical as underlined by the researchers. Thus the mental representations need not to be iconic.

When we look at these patterns from the point of view of the aspects to be captured in these mental representations, the third pattern dramatically differs from the first two. I think this mainly results from the demands of the task. Inferring the relative spatial directions of objects in a 3D large scale configuration with respect to the body does not implicate capturing visual aspects of these objects or their absolute relative locations in 3D space. Naturally, in this third pattern the mental representations neither need to embody visual aspects of the space or the objects in space nor need to have a 3D spatial structure similar to that of the represented space. Based on the findings in this their pattern, Bryant and Tversky et al. (2001) argues that people's mental models of the space represent conceptions of space rather than perceptions of it. These researchers underline this as a fundamental difference between the mental models of the spaces and mental images. Yet, when I consider that these tasks did not implicate capturing the visual aspects or the spatial structure of the space and can be carried out by constructing

even categorical representations, I come to the conclusion that the findings that people constructed a mental model of the space based on the central axes of their body in this task does not necessarily mean that this would be the case if one would need to capture both visual and spatial aspects of the space in a task. As I underlined previously, large scale spaces requires multiple viewpoints for apprehension of their visuospatial aspects. Accordingly, I suggested that it is very likely that even in cases where people need to construct visuospatial representations of a surrounding space based on perception; it would not be like snapshots of the space taken from multiple viewpoints. In other words, their mental representations would not be bound to a specific viewpoint. I further suggest that in constructing a mental representation of such a large scale environment upon viewing it in reality one would need an organizational spatial structure to integrate the visuospatial aspects captured from each viewpoint to another and thereby to have a visuospatial mental representation of the overall surroundings. One question is whether this spatial structure would be similar to that of the represented building space/form or would be a structure that is established based on the body axes.

In this study, I inferred that in the 3D mental representations that they constructed during their LS visualization processes, the architects did not capture the visuospatial aspects of the visualized building space/form from a particular viewpoint. It is likely difficult or impossible to capture the appearance of a 3D building environment from a specific viewpoint. In these tasks the architects constructed these representations based on the 2D drawings of the buildings, but a similar observation was made in the tasks that they recalled a familiar building space's appearance from a particular viewpoint. These begin to support view that I presented before in that visuospatial representations of the surroundings in a large scale configuration such as building space or the exterior form of the building that people construct based on perception might not be viewpoint specific. Furthermore, that these architects were not able to capture the visuospatial aspects of the space from a particular viewpoint within mental representations suggests that Johnson-

Laird's (1989) proposal of mental images being 2D projections of 3D mental models from a specific viewpoint might not be a valid one.

In this study, it was inferred that architects' mental representations captured the visuospatial aspects of the visualized space/form with a 3D spatial structure similar to that of the building space/form itself; furthermore in their construction processes they constructed their mental representations based on a generic 3D frame-like model representation of the visualized space/form. This frame-like 3D generic model captured the relative locations of the components in 3D space and their relations. At this point, I suggest that 3D visuospatial mental representations of a building space/form, or a large scale 3D configuration, are very likely structured based on the 3D spatial structure of the building space/form rather than based on the axes of one's own body as suggested for spatial mental models of spatial relations (Bryant, Tversky et al. 2001). This needs to be investigated in future research.

At this point one begins to question: on what basis we differentiate two different representations as images or as mental models? Because if it is the differences of one being viewpoint specific while the other is not, I believe it will not be reasonable to differentiate two representations on this basis. As I presented above, the characteristics mental images have mostly been investigated based on 2D small scale stimuli and a natural outcome of this would be their being viewpoint specific much like the way we can perceive 2D small scale figures or configurations. Likewise, the viewpoint specificity of mental representations of 3D small scale objects would mostly be dependent on the demands of the task. What would make such a mental representation a mental image would be that it captures the visuospatial aspects of this object from a viewpoint. Then this would mean that, in the case of mental rotation tasks, for instance, or in the case of the visualization tasks where architects imagined the buildings in 3D SS as in this study, we should consider such representations as mental models, whereas in the cases in which the tasks implicate capturing only viewpoint based representation of a 3D small scale

object for making the inferences, we should consider the created representation as a mental image. In any other possible cases which require capturing visuospatial aspects of a large scale configuration that can normally be captured from multiple viewpoints, or with multiple sightline adjustments, we should consider the constructed mental representation as a mental model as it would very likely be not viewpoint specific.

One other fundamental difference, on the basis of which models have been conceptualized as different from mental images, was the conception of images as vivid detailed representations embodying shapes, sizes, of objects as well as their spatial relations. As I outlined above, evidence suggests two types of mental images as visual and spatial images and spatial images are not vivid holistic visual representations rather they are more schematic representations. In this respect a spatial image is much like a mental model of a 2D figure capturing the spatial configuration of the figure which embodies visual representations of the component shapes of the object or object shapes in an array.

So far mental imagery has been investigated by a bottom up approach by studying elementary processes while mental models have been studied by a top down approach by looking at the mental representations in the context of complex reasoning processes. In imagery framework, these elementary processes have mostly been investigated by means of 2D small scale or 3D projection views of 3D small scale stimuli. On the contrary in mental modeling framework, the tasks in the context of which the nature of underlying mental models have been investigated, pertained to variety of domains and implicated variety of information to be captured. Accordingly, our understanding about the nature of the mental representations has remained situated in the tasks through which they are investigated.

Overall, when we look at mental models and images from the above perspectives, I suggest that we can consider both mental representations as instantiations of a common form of mental representation which I would define as perceptual mental models, or

iconic modal mental models, where the visuospatial aspects of a 2D figure or of a projection view of 3D SS object or large scale configuration are captured schematically by preserving the constraints inherent to what is represented.

At this point, I want to outline some similarities that I interpret between construction of multipart mental images as accounted for by Kosslyn (1994) and architects' stepwise construction of 3D SS or LS mental representations of the building space/form during their visualization processes as inferred in this study. I believe these similarities begin to provide a plausible account for the construction of representations that capture the visuospatial aspects of the world. In Kosslyn's account, multipart image generation can be accomplished using the same mechanisms that are used in encoding an image during perception. During perception, one typically encodes the overall shape first which will be low in resolution i.e. whose individual parts will not be very clear. Then after encoding the overall shape, its parts will be inspected and encoded one at a time as well as the spatial relations among them. In a parallel way, during image generation, a global image ("skeletal image") will be formed first, and since this global image will be low in resolution – and so not be very clear in terms of the individual parts – if a higher resolution of parts is needed, then more detailed representations of the parts and properties will be integrated into the global image one at a time. The more are the parts to be added to the image, the longer it takes to visualize. Kosslyn also adds that images fade very quickly and suggests that probably the total amount of information that one can maintain at once in an image depends on how fast the parts of the image begins to fade and how fast s/he can refresh the image. Here I infer that certain parts of an image would very likely begin to fade when others are being added during the generation of images which has many parts to it all of which cannot be refreshed at once. In such a case what is being maintained would be much like the global image involving some parts with higher resolutions but not all at once.

The architects' mental representations of the visualized building space/form, like the multipart images, embody multiple components and the spatial relations among them. Like the generation of multipart images on the basis of a global image, the architects' mental representations are being generated in a stepwise fashion on the basis of a generic frame-like 3D representation of the visualized building space/form. Architects were plausibly not maintaining a fully detailed 3D mental representation of the visualized building space/form as they generate it during their visualization processes; rather they were maintaining a 3D generic representation which involves detailed renderings of some of the components at a time and in which the components that are rendered actively changes throughout the visualization process. Overall, when I consider that both architects' mental representations of the visualized building spaces or forms and the visual images are representations of the visuospatial aspects of the world, these parallels between their construction processes makes a lot of sense. Furthermore, they begin to suggest a common account for how the human cognitive system could be constructing mental representations that capture the visuospatial aspects of the world which needs to be investigated in future research.

7.3.2 Gestures

The participants in this study were observed to produce extensive amount of gestures while describing their visualizations. The gestures produced by these participants were found to convey substantial amount of visuospatial information that was not available in their speech. In these respects, the visualization protocols of the architects in this study, provided one further exemplar of the extensive production of gestures when carrying out spatial tasks (Alibali, Heath et al. 2001; Wesp, Hess et al. 2001; Kita and Özyürek 2003; Morsella and Krauss 2004) and of the gestures conveying information that is not available in speech as have been documented in cognitive science literature (e.g. Church and Goldin-Meadow 1986; Schwartz and Black 1996a).

Furthermore, the gestures in architects' verbal descriptions provided various insights to this research on the nature of the architects' underlying mental representations of the visualized building space/form. In this regard, they presented a further example for gestures' providing a unique window into the speakers' mental representations as have been documented by previous research in gestures (Perry, Church et al. 1988; McNeill 1992; Crowder and Newman 1993; Goldin-Meadow 2003).

In addition to the above, based on my examination of the gestures, my understanding is that gestures that architects produced during their verbal descriptions were external representations corresponding to aspects of the imagistic 3D SS or LS models that architects have been constructing in their WM during their visualization processes. These gestures were an integral part of the visualization process in that they supported the creation of the imagistic models. In their concurrent descriptions of their visualizations (while building a coherent 3D invisible SS or LS model of the visualized building space/form in a stepwise fashion in their gesture spaces) the architects by moving their hands in their gesture spaces were concurrently shaping their imagistic models in their mental spaces. Their gesture models were helping them to concretize their imagistic models, the dimensions of the space and the components in the external space. The gestures were providing the architects immediate feedback about such things as the spatial distances among the components, their dimensions and connections in space. They were helping them to extend the imagistic models beyond the space of the mind to the space of the world and maintain them in a distributed fashion. This way they were not only in part off loading memory but also moving part of the architects' cognitive processing to their gesture space. In this respect the visualization processes of the architects were indeed an interactive process where the gesture and mental models were forming a 'coupled system' of internal and external representations (Nersessian, Kurz-Milcke et al. 2003; Hegarty 2004; Nersessian 2005).

Based on these inferences, I suggest that architects extensive production of gestures while carrying out the 3D mental visualization tasks, where they generated imagistic representations of the building spaces or form that they have never experienced before, not only was helping them to convey information that can not be easily conveyed in speech or helping maintaining spatial imagery, as previously proposed by Wesp and Hess et al. (2001) but also were also supporting their creation of those imagistic representations by distributing the processing and load between the space of the mind and the world, – that is, forming a coupled system of mental and external representations. In these respects, gestures can be very valuable tools not only for design thinking but visuospatial thinking in general and they can be encouraged to be used as a medium of design thinking by students.

7.3.3 Small Scale and Large Scale Spatial Abilities

Both the mechanical engineering and architecture participants in this study have been carrying out 3D mental visualization practices in the course of their design processes. Yet, mechanical engineering participants performed significantly lower than the architects in the 3D mental visualization tasks. On the contrary, the mechanical engineering participants had significantly higher SVAs than architects as measured by the paper folding test.

One fundamental difference between these participants was the scale of the entities that they were specialized in designing and thereby have been visualizing in the course of their design processes. All the mechanical engineering participants in this study were specialized in the design of small scale entities which can be apprehended from a single vantage point. On the contrary all the architecture participants were specialized in design of buildings which are large scale entities which cannot be completely apprehended from a single vantage point and whose apprehension requires capturing of sequences of views either by changing the line of sights such a by turning the head

around or by locomotion. In these respects the scale of the entities that mechanical engineering participants have been dealing with in their design practices were very similar to the scale of entities that are involved in the paper folding test which are also small scale abstract objects that can be apprehended from a single vantage point.

Based on the above considerations, my understanding and hypotheses is that 3D mental visualization of large scale building environments involves some capacities and processes that are not involved in visualization of 3D small scale objects. This was why (1) mechanical engineers, although having higher SVAs than architects, had performed significantly less well than architects in the 3D mental visualization tasks in this study and (2) no relationship was found between 3D mental visualization performances and SVAs in this study. I believe this was also why (1) Akin (2003) found that as the years advance, students of architecture become less efficient in their skills in manipulating small scale 3D rectangular blocks, (2) Yukhina (2007) and Ho (2006) did not find any consistent relationship between spatial abilities of architecture students as measured by the tests that involve small scale stimuli and their design and/or academic performances and their years of study, (3) various studies found only weak correlations or partial associations between small scale and large scale visualization abilities (as reviewed by Hegarty and Waller 2005), and (4) various studies found significant correlations between spatial abilities as measured by the paper pencil tests that involve small scale stimuli and performance in tasks that involve manipulation of small scale objects (Hegarty and Sims 1994; Hegarty and Steinhoff 1997; Field 1999; Németh 2007).

One of the interpretations made in the study reported here is that 3D LS visualization of buildings involves some capacities and processes that are not involved in visualization of the building in 3D SS. At this point, one begins to wonder whether these differences in 3D LS and SS visualization skills could be an outcome of the differences in the scale in which the building is mentally visualized. In order to take the first step to investigate this, I looked at the relationships between 6 LSV architects and 5 SSV

architects' 3D mental visualization performances and their SVAs and did not find any statistically significant correlation between them. Yet, these relationships need to be further investigated by a larger population to reach at a conclusion.

CHAPTER 8

CONCLUSIONS

This thesis presented a research study which was conducted with the aim of developing an in-depth understanding about the 3D mental visualization practices and capabilities of architects on the basis of four research questions:

- (1) What is the nature of the 3D mental visualization phenomenon architects claim to experience when imagining a building space/form or walking inside/outside a building?
 - a. What are the features of these 3D mental visualizations as evidenced in specific tasks?
 - b. What might be the nature of the mental representations that are created during these visualization processes?
- (2) Can every architect mentally visualize a building in 3D based on its 2D drawings; might there be individual differences among architects in their 3D mental visualization performances?
- (3) Might 3D mental visualization of buildings be only an architectural skill?
 - a. Can non-architects, who can read 2D architectural drawings, visualize a building in 3D based on its 2D drawings?
 - b. Can they do so to the same levels of performance as those of architects?
- (4) Might performance in 3D mental visualization be related to/predicted by SVA?

The study was conducted with 14 graduate students from architecture and 7 graduate students from mechanical engineering with one participant at a time in two sessions which were scheduled based on the participants' schedules. The first session of the study was carried in a silent room and was video-recorded. Time taken by the

participants to complete this session varied from 1 hour and 18 minutes to 3 hours and 8 minutes with a total of 45 hours and 18 minutes. The second session was carried out in part inside a silent room and in part inside the interior gallery space of participants' department buildings. The time taken by the participants to complete the second session of the study (excluding the travel time to their department buildings) varied between 20 minutes to 55 minutes with a total of 10 hour and 3 minutes; within this total 6 hours and 33 minutes was spent in their department buildings.

In this session, the participants were first asked a series of questions about their educational background and interviewed about their employment of 3D mental visualization practices in their design practices. Then they were asked to recall, imagine and describe the appearance of an interior space and exterior form of a building that they were familiar with, their department buildings, from given locations and to draw the imagined appearance of the interior space. These recall tasks were followed by the 3D mental visualization tasks where the participants were given 2D drawings of two house designs one at a time and requested to study the drawings for 10 minutes in order to visualize the first buildings, B1, from the interior and the second building, B2, from the exterior by imagining themselves walking inside B1 and around B2. After the study session, the drawings are collected back and participants were asked to describe their visualizations of the B1's/B2's interior/exterior spaces/form when imagining walking. They were also given spontaneous locations inside B1 and outside B2 and asked to visualize and describe what they would see ahead of them if they were to be standing at those locations. At one location in each building, just after their verbal descriptions of their visualizations, they were also asked to generate a drawing of the imagined appearance of that space/form. After the participants completed these tasks, they were interviewed about their 3D mental visualization experiences in the study.

In the second session, the participants were first given a paper-pencil test of spatial visualization ability. Then they were taken to their department buildings, which

they recalled and imagined in the first session of the study, and were requested to generate a perspective drawing of the interior space of this building by looking at it from the same location that they imagined this space in the first session of the study.

Two groups of analyses were conducted on the study data. The first group of analyses, which focused on the data collected from all participants, aimed at addressing the research questions, 2, 3 and 4 raised in this thesis. The first of these analyses was the performance analysis in which the participants' drawings (as the primary source) and verbal descriptions (as the supplementary source) of their visualizations of interior space of B1 and the exterior form of B2 from the two given respective locations were examined from the perspective of the completeness and accuracy of the 3D building information rendered in them based on a component-based evaluation scheme. The following sets of statistical analyses of performance were conducted: (1) analysis of the differences between architecture and mechanical engineering participants' 3D mental visualization performances in the interior and exterior visualization tasks by T-tests (2) analysis of the relationship between the participants' performances in the visualization tasks and their SVA levels by bivariate correlation/regression analyses (3) analysis of the differences between architecture and mechanical engineering participants levels of SVA by bivariate correlation/regression analyses and (4) analysis of the relationship between participants 3D mental visualization performances and years of work experience and years passed since their last design.

From the results of the first set of analyses, the conclusion drawn with regard to the second research question is that all the architects and architecture students can possibly visualize a building in 3D based on its 2D drawings but they can do so at different levels of completeness and accuracy i.e. performance. These individual differences in 3D mental visualization performance are likely not related to differences in the number of years of work experience they have or the number of years that has passed since their last design. The conclusion reached with regard to the third research question

is that 3D mental visualization of buildings is mostly an architectural skill in that it relies on certain abilities that become heightened in architects most likely more during education than in the context of professional practice. From the results of the first group of analyses, the answer derived to the fourth research question is that 3D mental visualization performance cannot be predicted by or related to SVA as measured by paper-folding test, and very likely as by other paper pencil tests of SVA.

The second group of analyses was conducted on the data collected from the architecture participants in the study with the aim to address the first research question raised in this thesis i.e. to develop an understanding about the features of their visualizations and the nature of the mental representations they created during these visualization processes. The first analysis in this group was the analysis of gestures where the depictive gestures that architecture participants produced along with their verbal descriptions of their 3D mental visualizations in each of the 5 visualization tasks were examined for understanding the features of their visualizations and inferring the characteristics of the underlying mental representations. In the second analysis in this group the drawings that these architecture participants generated from their mental visualizations of the interior space of B1 and exterior form of B2 from the two given respective locations were comparatively examined with the drawings that they generated when looking at the interior space of their department buildings from the given location on the basis of a number of characteristics. The objective of this analysis was to understand whether the way these participants captured the 3D appearance of the visualized building space/form from the given location in their mental representations of them would be similar to or different from the way the appearance of that building space/form would be captured from that given location in reality. The last analysis in this group was comparative analysis of the drawings that participants generated (1) from their 3D mental visualizations of the building space/form from the given locations (2) from their imaginations of the appearance of the interior space of their department buildings

from the given location and (3) when looking at the interior space of their department buildings from the given location. The objective of this analysis was to explore whether there could be some characteristics that pertain to drawings created from imagination (1 & 2) but not the drawings generated from perception (3) of building environments.

Based on the inferences made from these analyses, it is concluded that architects, when they say that they are mentally visualizing the buildings in 3D, can be visualizing the buildings in LS 3D i.e. by imagining themselves situated within (almost) the actual size 3D building environment, or in 3D SS i.e. by imagining a small scale model of the building or they can be predominantly visualizing in one of the two forms and alternatively switching to the other. Thus, architects in addition to visualizing a building by imagining themselves at a certain location or walking within the building environment, can be basically visualizing the building in 3D SS from one or series of directions. When visualizing the building in 3D SS from series of directions, architects can be doing so by imagining rotating or themselves rotating around a SS model of the building or by imagining discrete 3D SS models of the portions of the building that would be visible from each direction.

It appears that the architects, while visualizing a building in 3D LS from a stationary location or in 3D SS from a certain side, are actively constructing and revising an iconic modal mental representation of the visualized building space/form in their WMs in a stepwise fashion. They are first creating a very generic frame-like representation of the visualized building space/form in which captures the proportional distances of the space/form, the relative locations of the components in the 3D space, and possibly silhouette-like renderings of the components with a structure similar to that of the spatial structure of a 3D LS or SS model of the visualized building space. Then they are continuously revising these mental representations by fitting in more detailed visual-perception based, or modal, representations of the 3D building components to this generic model one at a time in a stepwise fashion. During this construction process the architects

are plausibly not maintaining all the added detailed representations of the components in their WM but rather off-loading them at certain intervals by encoding them to their corresponding LTM representations of the visualized building space/form. In creation of their mental representations, architects are concurrently making inferences by drawing upon LTM information other than the visuospatial information attained from the 2D drawings of the building. During this active construction process, in the cases where the architects are concurrently rendering the visuospatial aspects of the visualized building space/form in the gesture spaces, these concurrent productions of depictive gestures could be supporting these architects creation of their mental representations of the building space/form by distributing the processing and load between the space of the mind and the world. In other words the imagistic models and the gestures models could be forming a coupled system of mental and external representations leading to an interactive visualization process.

During this construction process, the way these architects capture the various visuospatial aspects of the building space in their 3D SS or LS mental representations is not the way they would be captured from a specific viewpoint in reality. Indeed, capturing the appearance of a 3D building environment from a specific viewpoint in imagination appears to be quite difficult or impossible in such imaginings where that 3D appearance has never been captured from in reality or from a real-world representation. Their visuospatial experiences are not like the continuous holistic visuospatial experience that one would have when looking at a 3D SS or LS model of the building; rather they are dynamic experiences where the visuospatial aspects of the building that are captured in detail continually changes.

In the cases where they say that they are visualizing the buildings by imagining themselves walking, the architects are mostly visualizing the various spaces/sides of the building by imagining themselves at a series of locations on a path in a motionless manner. It is very likely that during their visualizations, these architects are also

intermittently visualizing some portions of the floor/site layout, or their gestures indicate that they are taking “quick looks” at the 2D drawings of the building, for keeping track of their relative positions in the layout. During such imaginings, some architects can also be occasionally switching to 3D SS for visualizing some portions of the building for short episodes, for instance, at the instances where they find it difficult to or can not visualize in LS 3D or more efficient to visualize in 3D SS. Overall, it appears that what these architects experience in such imaginings of walking is much like a collage of the series of the dynamic visuospatial experiences one would have when visualizing a building from a certain location in a motionless manner, blended with intermittent experiences of visualizing a 2D SS layout and maybe with one or a number of the experiences one would have when imagining a portion of a building in 3D SS.

Some further conclusions drawn in this study with regard to these two major forms of 3D mental visualization in architecture are that 3D LS visualization (1) puts greater demands on the cognitive capacities and processes than 3D SS visualization and (2) relies on some abilities and processes that are not involved in 3D SS visualization and (3) could be a less common skill among architects.

The overall understanding attained in this study has several significant implications for architectural education and practice. First of all the inferred characteristics of the mental representations that architects create tells us that such visualization practices can be relied on in communicative and design processes for having an apprehension of the 3D spatial structure and the visuospatial aspects of a building in 3D LS or in 3D SS. Yet, the experiences that architects have during such visualizations should not be considered and counted on as the holistic visuospatial experience that one would have when looking at a building from a certain location within or looking at a SS model of a building from a certain point outside the model. Likewise when architects say they are imagining walking, the experience they have should not be considered as the continuous visuospatial experience of walking. Furthermore architects while carrying out

these visualization practices should not be considered as visualizing the building solely in 3D LS or 3D SS at the time, but rather possibly switching between these two forms of visualization.

Secondly, instructors or the students in the educational contexts or the architects in the practice should not basically assume that their students or their colleagues have the capability of mentally visualizing a building in 3D LS or that they are having a complete and accurate apprehension of 3D building layout in 3D SS or LS when looking at the 2D drawings of a building or the 2D sketches that they are currently communicating through or working with. Likewise not every architecture student or architect should be expected to be conceptualizing their design ideas by imagining the buildings from within.

Clearly, students or architects who have low level 3D mental visualization skills or who are not able to completely or accurately visualize and thereby conceptualize their designs from a within perspective could have various problems or deficiencies in their design practices. For instance, in the context of their design processes, lack of these abilities could lead to a need for external aids for visualization, which then could lead to the need for new skills for adapting these aids to the design process and further lead to different processes and typologies of design thinking. Likewise, in the context of the communicative practices such as, in collaborative design processes or project reviews, two designers having different levels of visualization skills or one of them having limitations in visualizing in 3D LS, could mean that these two different designers indeed would have different conceptions of a building space in 3D as well as would be capturing them at different levels of completeness and accuracy.

All the above implications raise two important closely related yet difficult questions to answer: Can we predict these skills prior to education? How these 3D mental visualization skills can be improved? As understood in this study, 3D mental visualization skills rely on some abilities that become heightened in architects, most likely to a large extent during education. The question then becomes how we can support

improvement of 3D mental visualization skills in the context of the architectural design education? What educational interventions can we make to foster development of these skills?

What makes the above questions difficult to answer is the fact that at this point, we do not know what could be the abilities that underlie these skills. Further, what might be the specific educational training and practices that have been supporting development of these skills? Deriving answers to both questions require unfolding various sub questions each of which require series of studies as I will discuss later.

At this point, what we have learned from this study with regard to 3D mental visualization skills are that these skills cannot be predicted by spatial visualization ability as measured by the paper pencil tests, such as paper-folding test, and that 3D LS and SS visualization skills are, to a currently unknown extent, dissociated skills. Both have important implications for research in spatial cognition. The former implies that spatial cognition, such as in architectural design, cannot simply be understood on the basis of spatial abilities defined by existing paper-pencil tests of spatial ability that involve small scale stimuli. The later implies that we might be looking at two partially dissociated families of spatial abilities.

My hypothesis is that 3D mental visualization skills in architecture rely on certain set of abilities that are not involved in visualization of 3D SS objects that can be apprehended from a single vantage point. My intuition and preliminary hypothesis is that, 3D SS visualization skills in architecture could be more associated with spatial abilities as defined by paper pencil tests of spatial ability than 3D LS visualization skills. In the same line of thought, my intuition is that 3D SS visualization skills in architecture could be sharing more abilities with those that are involved in 3D mental visualization of small scale objects such as in mental visualization of a complex machine part in mechanical engineering.

There have been mainly two frameworks in cognitive science related to the issues raised in this study, in which the nature of the mental representations that capture visual and spatial aspects has been investigated: mental imagery and mental modeling. Mental images and mental models have been conceptualized as mental representations that are somewhat different in nature and these differences have been mostly pointed to in the mental modeling literature. The current understanding about the nature of these mental representations has been to a large extent established based on the research which investigated the nature of the mental representations of visual and spatial information in the context of tasks that implicate capturing visual and spatial aspects of 2D or 3D small scale objects. Thus, there has not been an in-depth investigation about the nature of mental representations that capture visual and spatial aspects of large scale configurations in cognitive science. In this regard the understanding attained in this study about the nature of mental representations that capture both the visual and spatial aspects of the buildings in two different scales, as 3D LS and 3D SS added on to the current body of knowledge about the nature of visuospatial representations. By doing so, as I presented in the previous chapter, this understanding has provided a different and integral perspective on the existing body of knowledge on the nature of visuospatial representations and lends support for an integral view of mental representations of the visuospatial aspects of the world rather than two different conceptions as mental imagery and mental models.

The understanding attained in this study with regard to the role of gestures lends support to previous findings of cognitive science research on gestures. While doing so it provides some further insights about how gestures could be contributing to thinking while carrying out spatial tasks; which is that they can be contributing to thinking by extending the cognitive processing beyond the space of the mind to the space of the world i.e. by forming a coupled system of internal and external representations. Until now, gesturing has not been studied much in contexts where the referred to objects are not present or in contexts of the kinds of tasks where the speaker creates a visuospatial representation of

an imagined 3D situation, a situation that has never been experienced. In this respect, my intuition is that gestures in these situations in general could be more of an integral part of the cognitive system than mere instantiations of imagination.

There have been some limitations in this study. One of the major limitations mainly stemmed from the limitedness of our current knowledge about 3D mental visualization in architects and thereby the extensiveness of the issues that need to be investigated. There have been mainly two different perspectives from which 3D mental visualization in architecture needed to be understood; as a cognitive practice and as a cognitive capability. So far our understanding of the 3D mental visualization practices as a cognitive practice has been mainly limited to what architects claim to be experiencing and how they claim to be benefiting from these practices. Likewise our understanding of 3D mental visualization capabilities has been mainly based on suppositions about architects being able to capture the 3D appearance of a building design during such visualization processes. As a first step in investigating architects' capabilities for carrying out these practices, we need to have an in-depth understanding about what role these practice might actually be playing in architects' design processes and practices. To do so, we first need to understand what they might be experiencing or what it is that they capture in their minds while carrying out these practices. This requires an in-depth investigation of these practices and thereby collection and analyses of various data from different perspectives. This path was selected in the design of this study, in that the priority has been given to first develop an in-depth understanding about 3D mental visualization as a cognitive practice. Yet, selecting this path, implicated a research design involving multiple tasks and requiring collection and analyses of extensive data, as well as a study procedure that need to be carried with one participant at a time in two sessions in an average of one and a half hours and half an hour respective. This requirement became a limitation on the investigation of the 3D mental visualization as a capability. It was not feasible to integrate more spatial ability measures due to the extensiveness of the

time required to carry out the study. It also was not be feasible to carry out the study with larger populations.

One set of limitations in this study arise from those common in investigating a cognitive practice and the nature of mental representations. The research had to rely on verbal descriptions, drawings and any other means of externalization, such as gestures, as the means to develop an understanding about the nature of the mental representations that informed creation of these external representations. Such an investigation requires qualitative methods of analysis. Furthermore, there is always the possibility of having a limited view of the mental processes because there is the risk that the participant might not be able to externalize their processes through the means that are available to them. Such possible limitations in externalization become more likely when studying spatial phenomenon, for instance, one's not being able to draw. I attempted to overcome these limitations in this study as much as possible by adapting measures such as using both verbal descriptions and drawings as means for externalization and analyzing both forms of data, additionally, only the 3D building information in the drawings was examined in performance analyses rather than the qualitative characteristics of the drawings.

A further limitation in this research, which was mostly an outcome of the time demands of the study procedure, was finding volunteers. The time demands of the study decreased the potential number of people who would volunteer in this study. Thus, even though the study participants were randomly selected there is always the possibility of "self selection" effects, that is, that the people who volunteered for the study would be those individuals who believe they have high visualization skills or who perhaps those who think that they would perform poorly in this study would not volunteer to participate., The only measure that was taken in this study to reduce the self selection possibility was the compensation fee provided to the participants for compensating their time. Yet, looking at the variance among the participants' 3D mental visualization

performances in the study, it can be concluded that if such a self selection occurred it had been minimal.

Having attained an in-depth understanding about the 3D mental visualization practices of architects, the next research step that needs to be taken for developing a comprehensive understanding of these practices in architecture in particular and of spatial cognition in architecture, more generally, is to develop an in-depth understanding about 3D mental visualization as a cognitive capability. Previously, I underlined two critical issues that need to be investigated in future studies: Can we predict these skills prior to education? And how we can support improvement of 3D mental visualization skills in the context of the architectural design education? I emphasized the difficulty in addressing these questions pointing to the fact that we need to take several steps first. For instance, in order to identify predictive measures for these skills we first need to devise measures for investigating the level of 3D mental visualization skills with larger populations. Then we need to investigate to what extent these skills can be accounted for and predicted by the existing measurable visual and spatial ability factors. There is the possibility that existing factors of spatial ability might not have a strong predictive power for identifying the 3D mental visualization skills. Such a case would mean that we need to begin to map out the possible ability factors that underlie these skills but cannot be tapped by current measurable factors. This would require understanding the component processes involved in 3D mental visualization to break it down to lower level skills. While these comprise some of the steps that we need to take for being able to predict these skills prior to education, investigating the means through which these skills can be improved raises various sub issues of its own other than requiring longitudinal studies which by it self would necessitate long research periods. In addition to the issues noted thus far, one further issue that needs to be investigated is the differences between 3D SS and LS visualization skills.

I have listed above some of the steps that need to be taken for developing an in-depth understanding of the 3D mental visualization as a capability, but there are several additional future directions I intend to pursue next towards improving our understanding of spatial cognition. One of the directions I intend to pursue is to test the hypothesis that I put forward in this study on the differences between 3D mental visualization of large scale building environments and small scale objects. As the first step I intend to establish and conduct mental visualization studies across different disciplines that deal with design of 3D small scale and large scale configurations. another line of research that I intend to pursue is to further the understanding I attained with regard to the 3D mental visualization processes as being instantiations of mental modeling practices. I intend to investigate the cognitive role of gestures in these mental modeling practices and further investigate these modeling practices in the context of design thinking processes on the basis of the model-based reasoning framework. One further direction I intend to pursue is investigating the interaction between 3D mental visualization skills and use of external visualization tools such as 3D modeling tools.

LIST OF ABBREVIATIONS

Table 19 List of Abbreviations

Abbreviation	Word/Phrase
<i>B</i>	<i>Building</i>
2D	Two Dimensional
3D	Three Dimensional
SS	Small Scale
LS	Large Scale
SSV	Small Scale Visualizing
LSV	Large Scale Visualizing
CD	Component Defining
RBS	Recalled Building Space
ABS	Actual Building Space
SVA	Spatial Visualization Ability
WM	Working Memory
LTM	Long Term Memory

APPENDIX 1

Table 20 Background Questions

Background questionnaire
(1) What is your undergraduate degree?
(2) When did you graduate from the university?
(3) Did you receive your undergraduate degree from a university in the United States or a foreign country?
(4) What is your current graduate program of study? When did you start this program?
(5) Have you had any work experience in this field—in architectural design or mechanical engineering—prior to attending your current graduate program; (if so) how many years of work experience did you have and what were your responsibilities?
(6) What was the last time that you carried out or were engaged in a design project?
(7) Do you have any other undergraduate or graduate degrees in any other fields?

Table 21 Pre-study interview guide

Pre-study interview guide
<p>Architects</p> <p>(1) Use of 3D mental visualization practices in the design process</p> <p>Possible question format: Can you tell me a little bit about what you generally do to work out the 3-dimensional aspects of your design?</p> <p>Alternative further question: While designing, do you tend to visualize the 3D aspects of your design? Can you describe to me or exemplify for me how you generally do it?</p> <p>(2) Can the participant visualize a building in 3D based on its 2D drawings?</p> <p>Possible question format:</p> <p>Possible format: When you look at 2D drawings of a design such as section and plans, can you interpret the building forms and spaces in 3D? Can you tell me how you do it?</p> <p>Mechanical Engineers:</p> <p>(1) Use of 3D mental visualization practices in the design process</p> <p>Possible question forma: Can you tell me a little bit about what you generally do to work out the 3-dimensional aspects of your design?</p> <p>Alternative further question: While designing, do you tend to visualize your design as a 3D entity?</p> <p>(2) Familiarity with orthographic drawing techniques such as the representation of a 3D object by generating multiple views, sections, plans, and elevations.</p> <p>Possible Question Format: Are you familiar with orthographic drawing techniques? 2D drawings, paraline (axonometric/isometric) projection drawings</p>

Table 22 Post-study interview guide

Post-study interview guide
<p>(1) How the visualization tasks were carried out</p> <p>Possible question format: Can you describe to me how you carried out the visualization tasks in this study?</p> <p>Alternative further question: For instance, how did you visualize what you would see in 3D if you were to walk through the building spaces or around the building in the first place?</p> <p>(2) The nature of these visualizations were in terms of their level of detail and vividness</p> <p>Possible question format: Can you tell me a little bit about the nature of your visualizations that you generated in this study?</p> <p>Alternative further question: How clear or vivid were your visualizations? Were they detailed or vague?</p> <p>(3) Differences in the interior and exterior visualization experiences</p> <p>Possible question format: Were there any differences between your interior and exterior visualization experiences?</p> <p>(4) Were there any particular challenges for you in carrying out these tasks?</p> <p>(5) Would you like to make any further comments about your experiences?</p>

Table 23 Description of 3D Mental Visualization Tasks & Procedure

3D Mental Visualization Study
<p>Description of Tasks:</p> <p>In this section, you will be given the plans and section drawings of 2 house designs one at a time. You will be required to study the 2D drawings of each building in order to visualize and learn the appearance of the building spaces and forms in 3 dimensions in as much detail as possible during a 10-minute study session.</p> <p>In visualizing the given house designs, you will be required to visualize the first house design from the interior and the second house design from the exterior.</p> <p>In visualizing the first house design from the interior:</p> <p>You are required to study the building's drawings to visualize what you would be seeing in 3D if you were to walk through the building's various interior spaces and look around to examine the appearance of these spaces and the elements within.</p> <p>After the study session, you will be required to</p> <ul style="list-style-type: none"> (1) Describe to the experimenter what you would be seeing in 3 dimensions (in terms of the elements and their forms) within the surrounding spaces while walking through the spaces inside the building. (2) Describe what you would be seeing in 3 dimensions from two different locations inside the building; these locations will be specified by the experimenter. (3) Generate a drawing of one or more of the described views of the building on paper. <p>In visualizing the second house design from the exterior:</p> <p>You are required to study the drawings of the house to visualize how the building would appear from the exterior from different directions if you were to walk around it and look at it to examine the appearance of the building form and elements.</p> <p>After the study session, you will be required to</p> <ul style="list-style-type: none"> (1) Describe to the experimenter the forms and elements of the building that you would be seeing in 3D from a particular location outside the building provided by the experimenter. (2) Describe what you would be seeing in 3D while walking around the building.

(3) Generate a drawing of one or more of the described views of the building on paper.

Description of the Procedure:

Given the plan and section drawings of each house design one at a time, you will first be asked to examine the drawings and read aloud all the information that you can read in each drawing or cross read from multiple drawings. During this read aloud process, you can direct any questions to the experimenter for any clarification about any symbol or part in the drawing that is not clear to you.

After examining and reading aloud all the drawings, you will be provided a 10-minute study time for each house design. During this time, you are required to visualize and learn the building in 3D either from the interior or exterior as discussed in the previous section. While studying the given drawings of the building for visualization, you are required to do so without using any paper, pencil, or any external media and solely by examining the given set of drawings.

After the study session, the experimenter will ask if you need more time to study the drawings and provide you time until you report that you are ready to proceed. You will then return the drawings of the building to the experimenter and be asked by the experimenter to carry out the mentioned visualization activities or drawing tasks.

The first building drawings will be presented to you when you inform the experimenter that you are ready to start. After you complete this first visualization task, you may take a break if you need. Then you will be given the drawing of the second building and told to proceed.

At any time during the overall experiment, you can inform the experimenter that you do not want to continue the experiment at that time or that you wish to withdraw from the experiment.

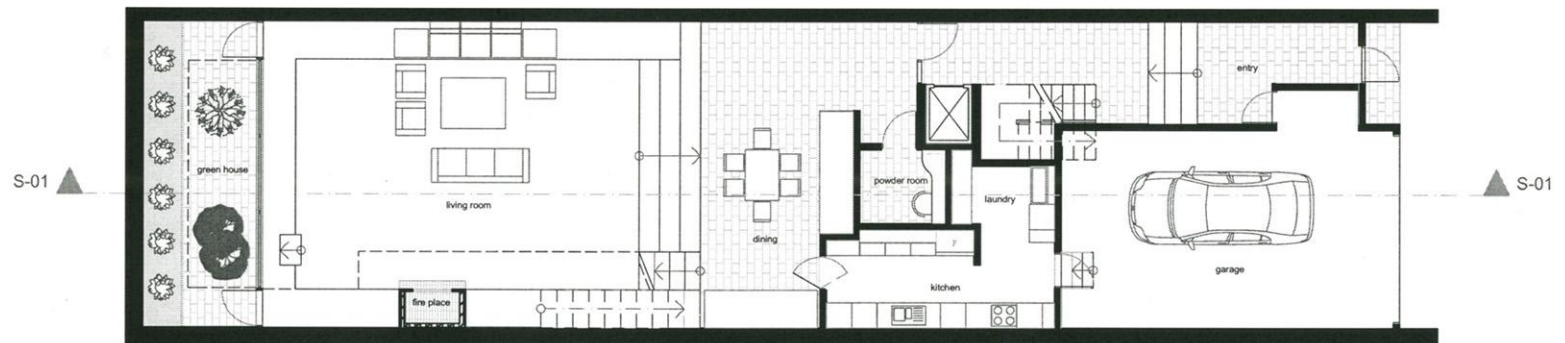
Thank you very much for participating in this study and for your time.

Have Fun

BUILDING 1- PLANS



1 FIRST FLOOR

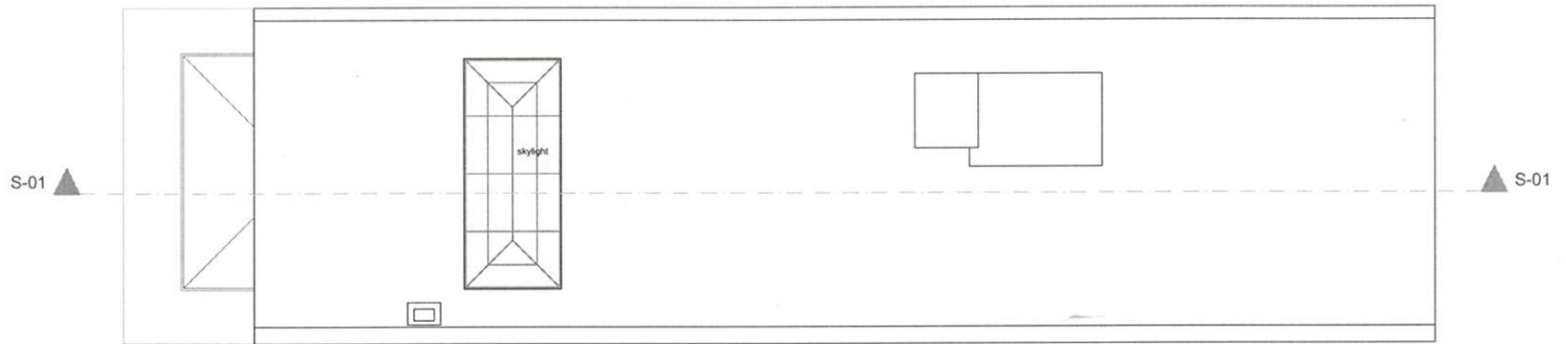


0 GROUND FLOOR

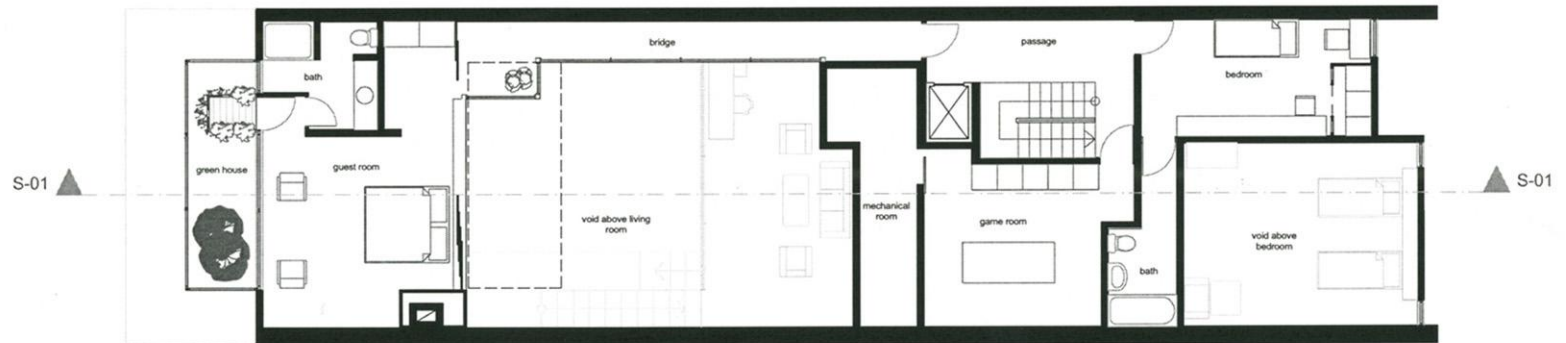


Figure 34 B1: ground floor and first floor plans

BUILDING 1- PLANS



3 ROOF



2 SECOND FLOOR



Figure 35 B1: second floor and roof level plans

BUILDING 1- SECTION 01

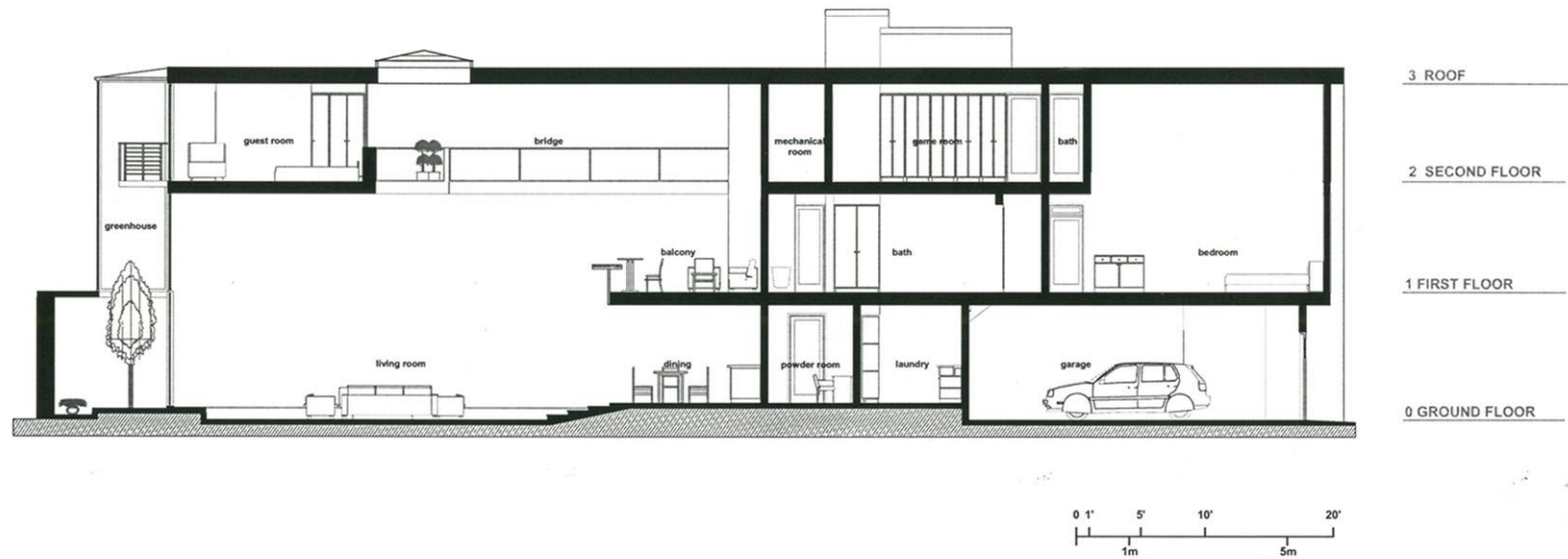


Figure 36 B1: section 01

BUILDING 2- PLANS

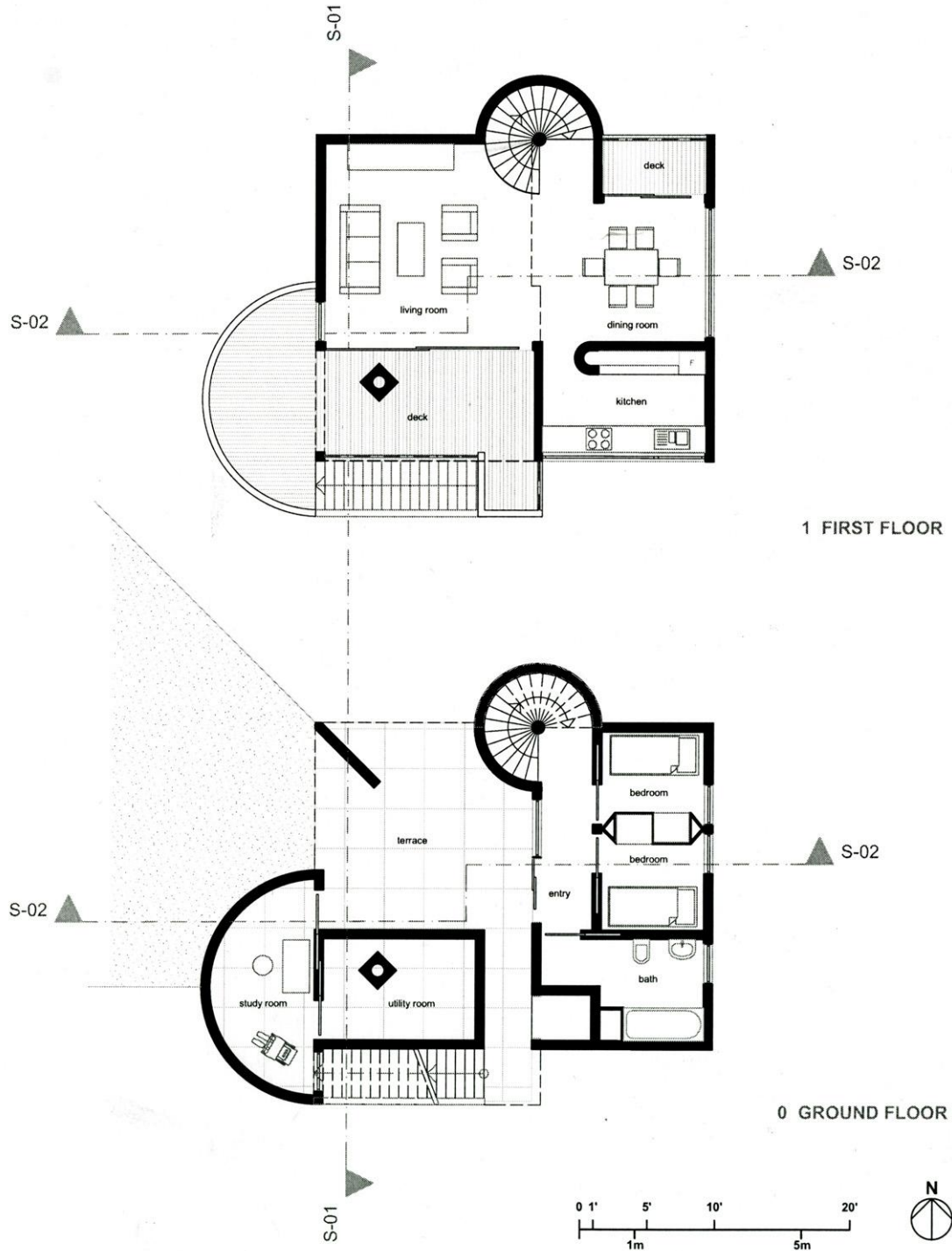


Figure 37 B2: ground floor and first floor plans

BUILDING 2- PLANS

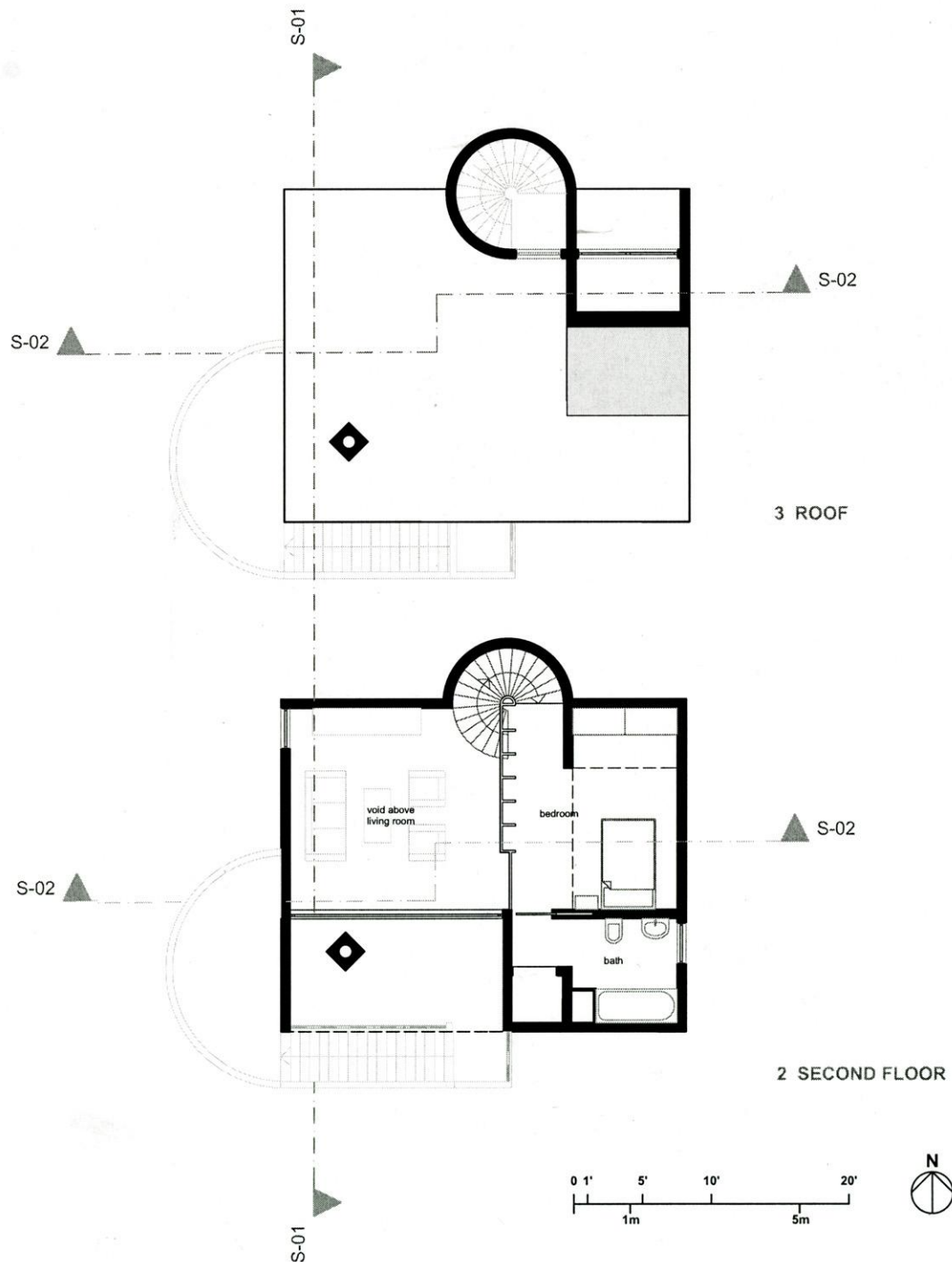
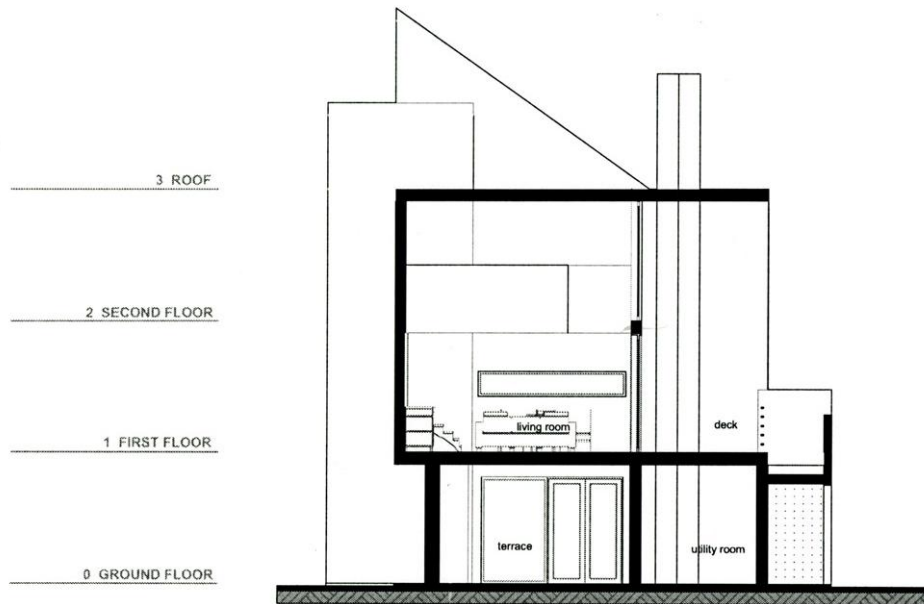
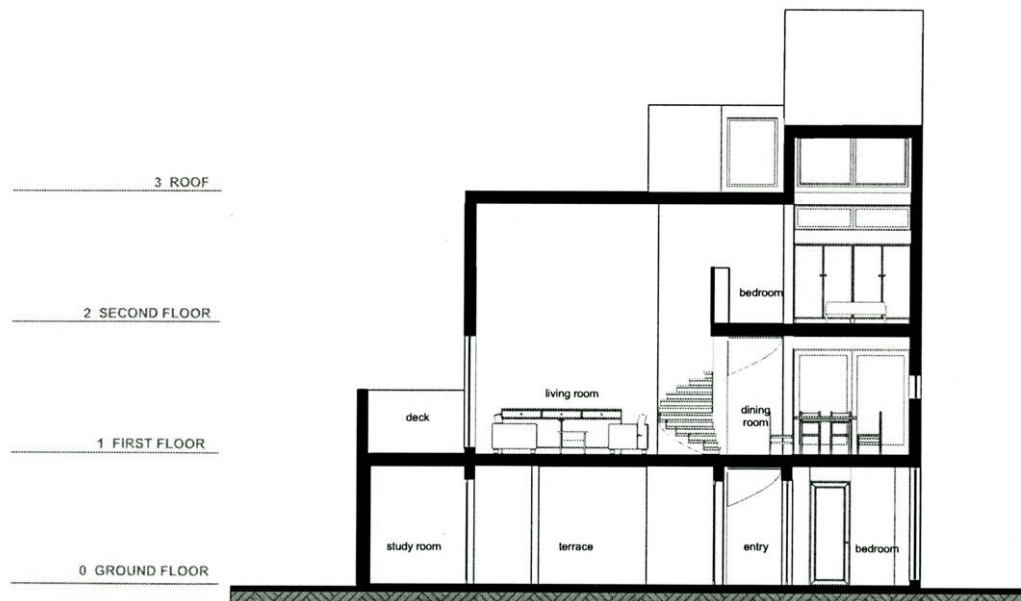


Figure 38 B2: second floor and roof level plans

BUILDING 2- SECTIONS



SECTION 01



SECTION 02

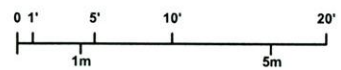


Figure 39 B2: sections 01 and 02

APPENDIX 2

Table 24 Portions from A4's micro level coding of verbal description of B1 from location 2 and the inferences drawn at Micro and Macro level Analyses.

Micro level coding of A4's verbal description of B1 from location 2			Inferences made at the Micro Level of Analysis	Inferences made at the Macro level of analysis
Verbal statements (gesture occurrences <u>underlined</u>)	Verbal description of the gesture	Information conveyed by gesture		
That's is a nice view I think, because you get to see aaa...I don't know it's the <u>guestrooms</u> ;	Raises his right arm and hand with index finger up above his head (around 7 inches) pointing to top	located over the head	He is located within the space at the given location where guestroom is up above	The participant is imagining the interior space of Building 1 as if he is within that space at the moment.
a room it's well <u>above</u>	He opens up his arm and his hand and shakes his hand with fingers pointing to the above	High above	Same with above	
so it's not <u>really</u> close to you anyway.	raises and shakes/waves his hands above at two sides with open palms in line with his head	It is above	Same with above	
But probably <u>you</u> get to <u>feel</u> <u>something there</u>	Raises his right arm and holds his right hand (20 cm) above his head his palm looking down in that his hand standing parallel to the floor twisted from his wrist – as if he is holding his hand under a horizontal surface – the back of his hand is touching that surface; then starting from that position he first moves his arm and hand as if continuing to sweep that horizontal surface and then after sweeping a certain distance, he rotates his hand into a vertical position with his palm facing front and continues to sweep a vertical surface by the back of his hand by raising his hand above	The guestroom slab is a horizontal surface covering above; represents the distance that the slab of the guestroom above continues in the forward direction and that at that front end of the guestroom slab lies a bounding wall that looks towards the gallery space	Same with above	

Table 24 continued

Verbal statements (gesture occurrences underlined)	Verbal description of the gesture	Information conveyed by gesture	Inferences made at the Micro Level of Analysis	Inferences made at the Macro level of analysis
But it's <u>way up</u> in this space]	Raises his left arm above with hand open and shakes his hand	(located above at a <u>distance – full arm height</u>	Same with above	
and what else, aaa, <u>that you see the stairs going up</u>	First takes his both hands above next to each other then opens his arms to sides-, hand palms facing forward 4 fingers together pointing towards forward higher than the thumb –like holding a horizontal bar located in the air, after opening up, while his left hand stands still at up, he takes his right hand down and moves it up while holding left up in the air,	there is a vertical rectangular longitudinal surface continuing in the front above from left of the space to right of the space and the stairs, which are moving from bottom to up in the forward direction toward that surface, are connecting to it at its right end	Same with above	
() <u>the railing</u> there	He repeats the first part of the previous gesture, holding a bar that continues to both sides in the front space above	a longitudinal rectangle located forward above continuing from left of the space to right of the space	Same with above	
() andddd aaaa	He stretches his right arm up front with his hand palm facing him and the back of the hand facing forward and moves his hand continuously from top to bottom in a vertical trajectory as if back of his hand is sweeping a vertical surface there	depicting a vertical surface parallel to him in the forward direction and continuing towards up	Same with above	
Switch to a different representation				

Table 24 continued

Verbal statements (gesture occurrences <u>underlined</u>)	Verbal description of the gesture	Information conveyed by gesture	Inferences made at the Micro Level of Analysis	Inferences made at the Macro level of analysis
Yee I don't remember if the wall <u>that's beneath dining room</u>	Opens his hands at a distance on the table palms facing each other fingers facing forward as if holding two sides of a rectangle	a rectangle shown on the table top	He is depicting the rectangular dining area as if being located on a small scale 2D layout or 3D model of the building	The participants is visualizing a 3D small scale model of that portion of building space from the side at a height which is approximately at the level of 3 rd floor in this small scale.
<u>the dining room</u>	Puts his right index finger on the table slightly to the left aligned with his left shoulder indicates the location of the dining room then continues to raise his hands by shaping them as if he is holding a rectangular protrusion	the wall is located behind the dining room	He continuously moves his hand as if he is tracing a rectangular protruding surface inside a 3D small scale model of the building	
<u>makes the sauna</u>	Following the location indicated in the previous gesture to a level around his chest, he raises his right hand up vertically ,while keeping to hold the rectangular mass, and makes a discrete emphasizing shake stop motion	sauna is located one floor above	Same with above	
<u>and other part of the bathroom</u> upstairs	Continuing the previous gesture he then moves his hand slightly to right while talking about bathroom	bathroom is located on the right of the sauna, wall bounds the sauna area in the upper floor and also the bathroom next to it	Same with above	

Table 24 continued

Verbal statements (gesture occurrences <u>underlined</u>)	Verbal description of the gesture	Information conveyed by gesture	Inferences made at the Micro Level of Analysis	Inferences made at the Macro level of analysis
<u>plus the machine room</u>	Following the previous gesture, he moves his right hand one more step up vertically from the location of the sauna in the same vertical axis to a level which is almost at the level of his head and points to that location above the sauna	located one floor above the sauna-bathroom area	Note: The increment of the height at which the mechanical room is located at in the vertical axis of the sauna indicates locating on a small scale 3D model Same with above	The participants is visualizing a 3D small scale model of that portion of building space from the side at a height which is approximately at the level of 3 rd floor in this small scale.
<u>if it's all the way up</u>	Arms are forward towards his front hand palms are facing each other oriented vertically and hold at a distance to each other. He starts to move the hands from bottom close to table surface to up a little above his head as if he is sweeping the surface of a vertically extruded rectangle from bottom to up	representing the shape of the wall as a rectangular prism continuing from bottom -table surface- to upper levels	Same with above	
<u>shaped in the same way</u>	Both his hands are raised at his head level slightly off to his left with palms facing forward and fingers pointing to top. First he moves his right hand slightly while holding the left hand still. Then he pushes his right hand to a slightly further vertical plane and continues to sweep a plane which is further- recessed and vertical.	the shape is represented as a surface on the forward left continuing to a certain distance to the right at the same plane and then immediately recessing back forming a recessed surface on the forward right	Same with above	
Switch back to previous representation				

Table 24 continued

Verbal statements (gesture occurrences <u>underlined</u>)	Verbal description of the gesture	Information conveyed by gesture	Inferences made at the Micro Level of Analysis	Inferences made at the Macro level of analysis
I think it , it must be, so you get to see <u>this shape there</u>	This time, repast the previous gesture at a larger scale as if at this time, he is looking at the wall surfaces in their actual sizes	re-represents the previous surface form	Shape of the walls are represented as if they are viewed in actual sizes from the given location Participant is visualizing the wall form as if he is inside that space standing at the given location	The participant is visualizing the interior space of Building 1 as if he is within in that space
<u>plus the railing</u> and so that's pretty much what you see	Takes his both hands above next to each then opens his arms to sides-, hand palms facing forward 4 fingers together pointing towards forward higher than the thumb –like holding a horizontal bar located in the air	a longitudinal rectangle located forward above continuing from left of the space to right of the space	Note: He generates the gesture that he previous generated for depicting the railing, at the same location and height Same with above	

Table 25 Review sheet provided to the external reviewer for his examination of the gestures in architecture participant's 3D mental visualization protocols

Number of the reviewed video file:

In the videos that you are going to watch, you are requested to pay particular attention to the gestures produced by the participant during the speech and select one of the following:

In this segment of video the participant appears to be describing that space/form/portion of the building by

- (1) imagining to be within that building environment
- (2) imagining that space/portion/form of the building much like in the form of a small scale model of the building
- (3) imagining a 2D small scale drawing of that portion of the layout
- (4) none of the above

Can you please briefly describe if you have any other observations:

Have you observed any gesture that seemed to be different than others in the way it depicts the building component/space/layout etc. If so could you please define this observed difference?

APPENDIX 3

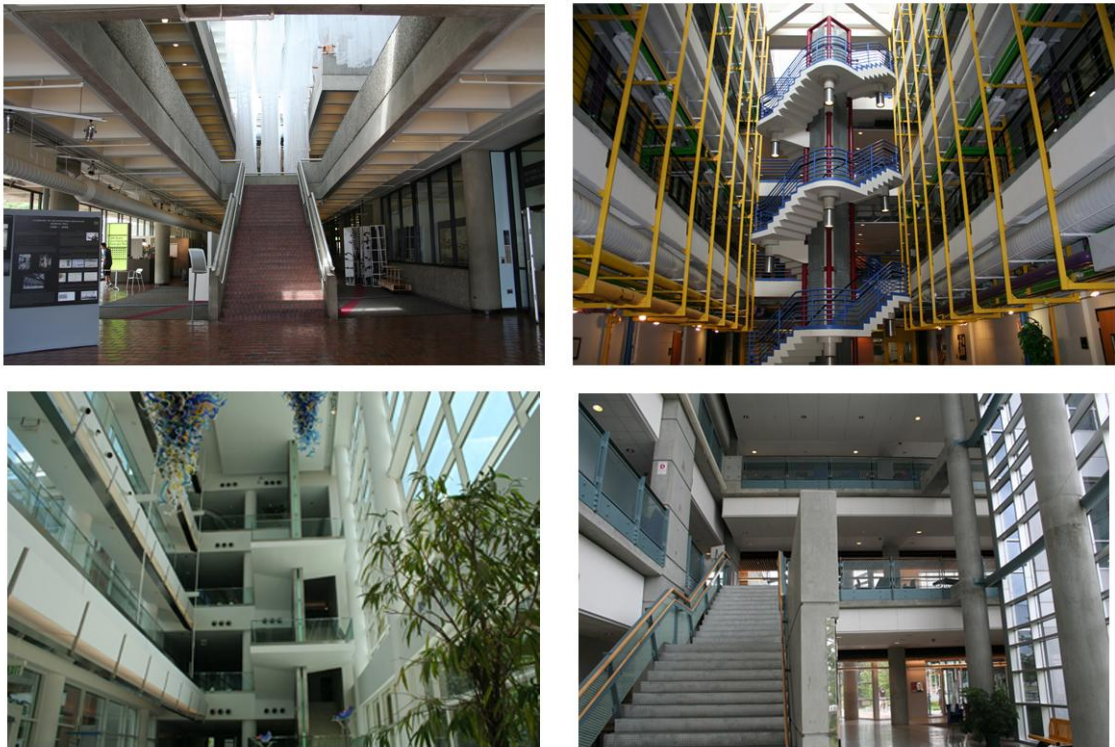
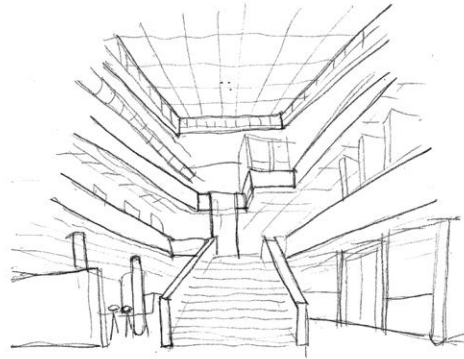


Figure 40 Pictures of the interior spaces of the participants' department/office buildings taken from the locations from which they were depicted in participants' drawings of ABS and RBS

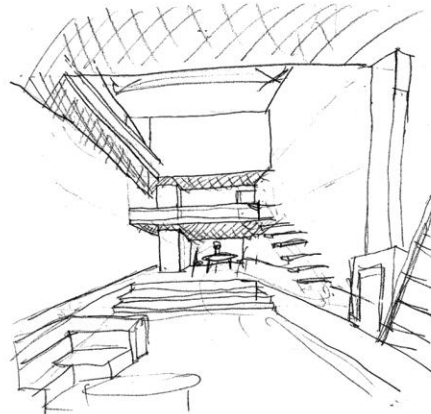
Drawings of A1



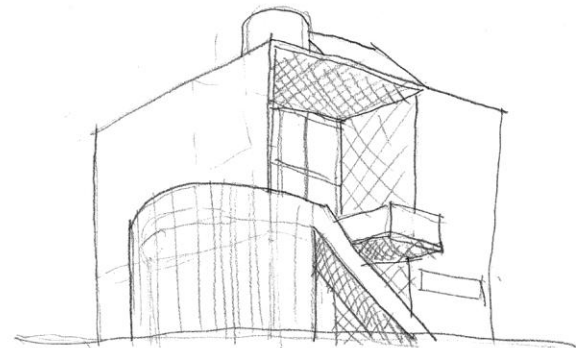
ABS



RBS



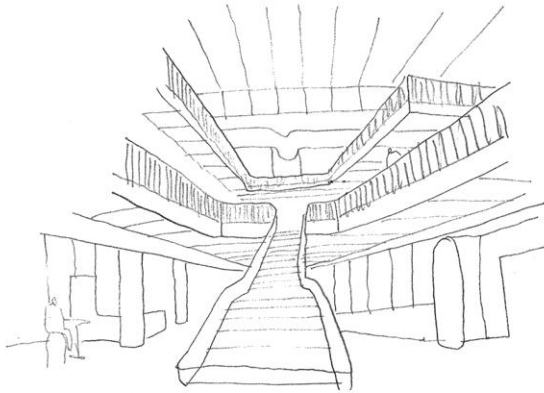
B1-L2



B2-L1

Figure 41 A1's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

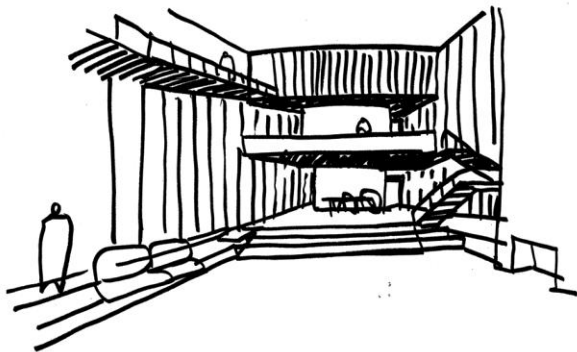
Drawings of A2



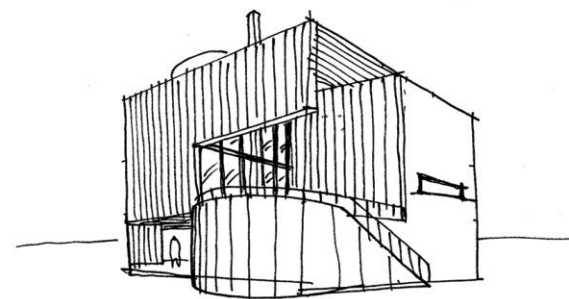
ABS



RBS



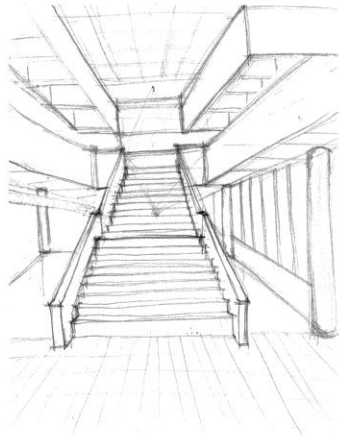
B1-L2



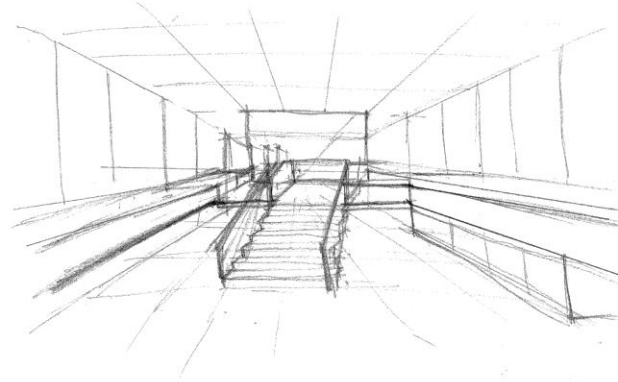
B2-L1

Figure 42 A2's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

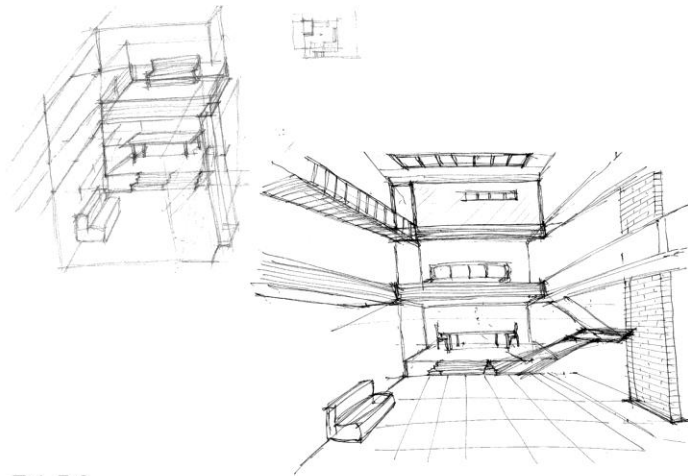
Drawings of A3



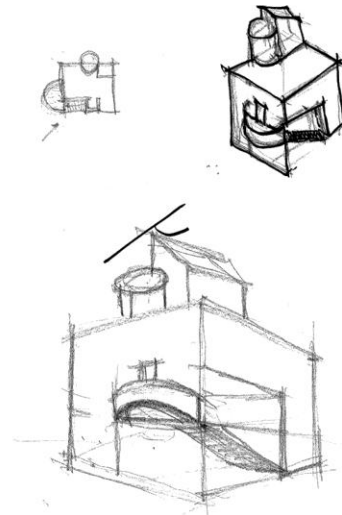
ABS



RBS



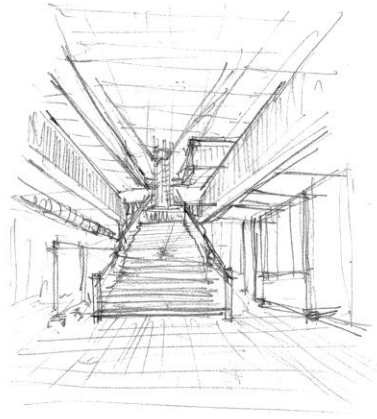
B1-L2



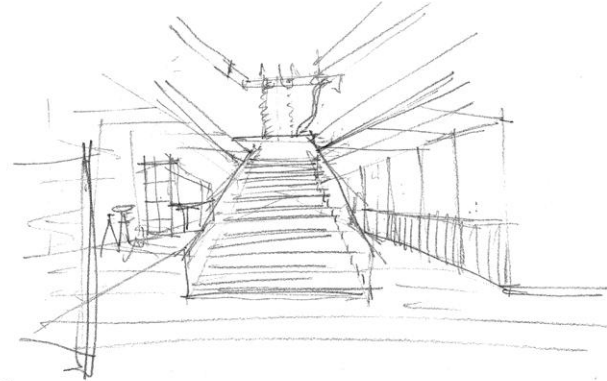
B2-L1

Figure 43 A3's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

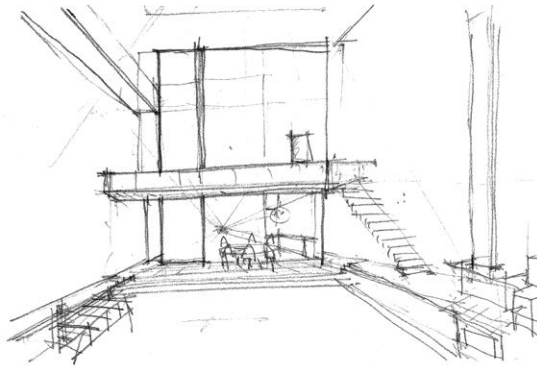
Drawings of A4



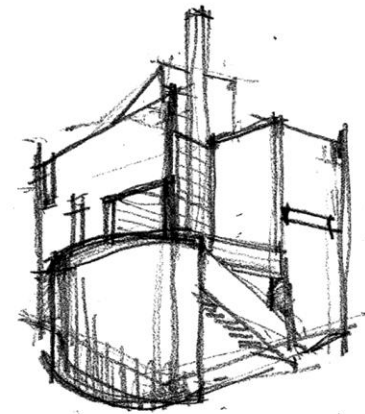
ABS



RBS



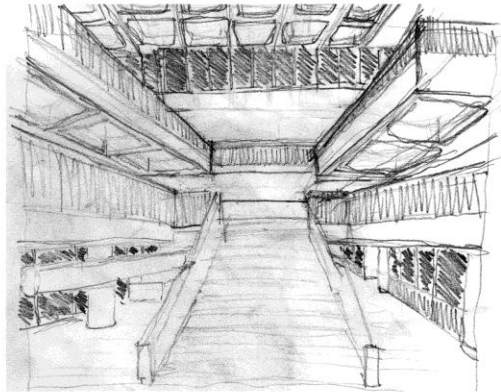
B1-L2



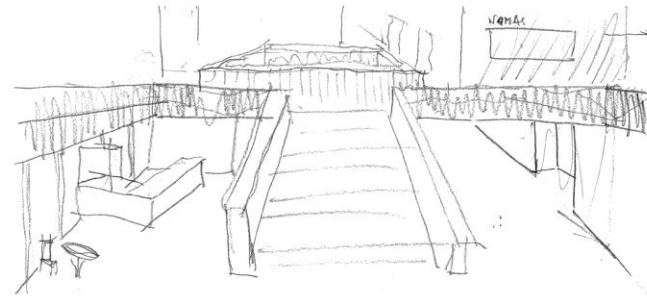
B2-L1

Figure 44 A4's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

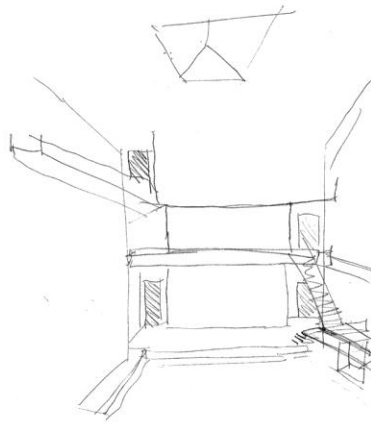
Drawings of A5



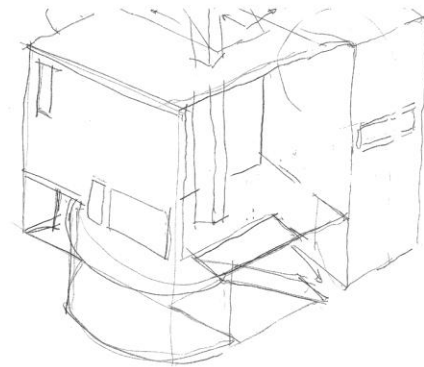
ABS



RBS



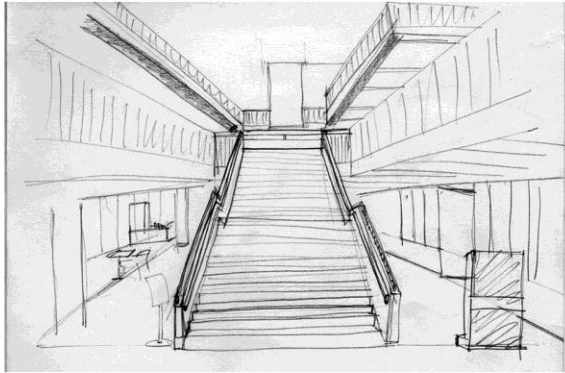
B1-L2



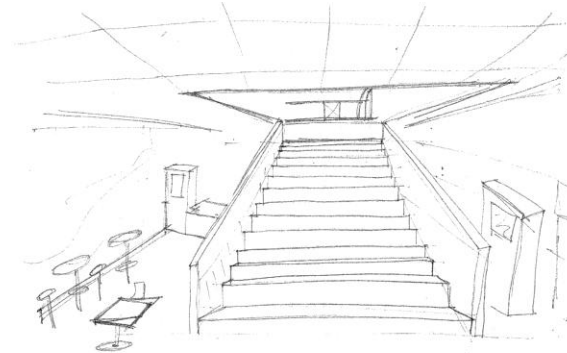
B2-L1

Figure 45 A5's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

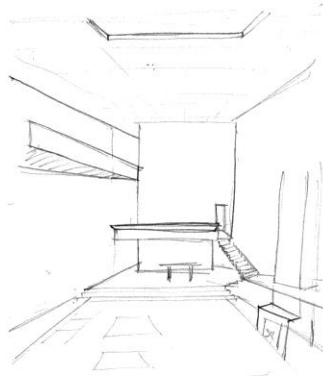
Drawings of A6



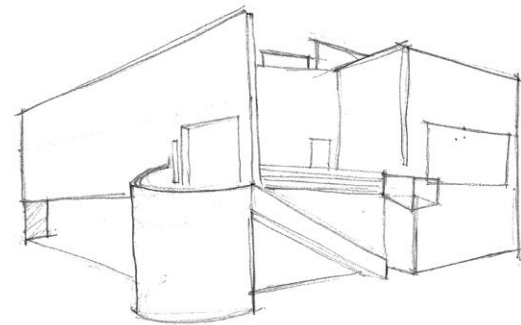
ABS



RBS



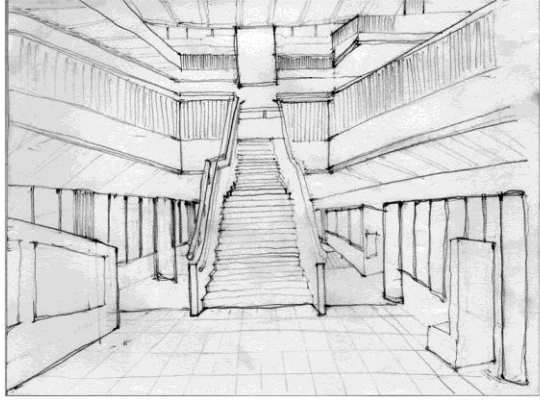
B1-L2



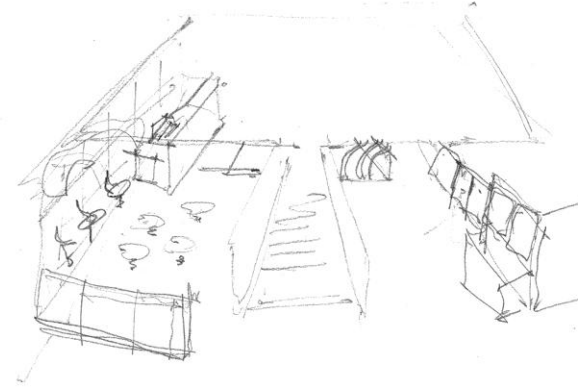
B2-L1

Figure 46 A6's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

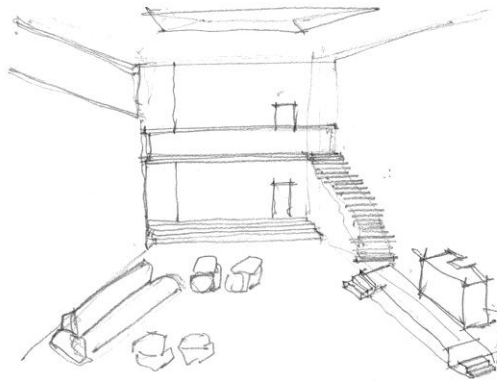
Drawings of A7



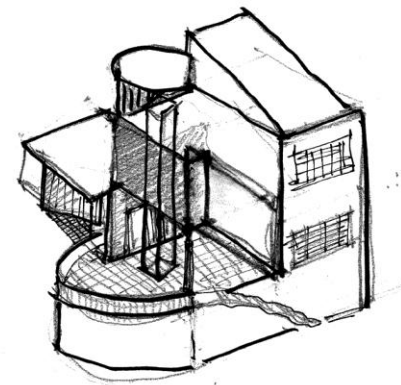
ABS



RBS



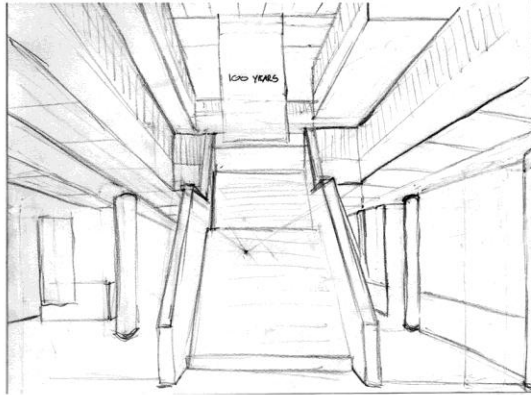
B1-L2



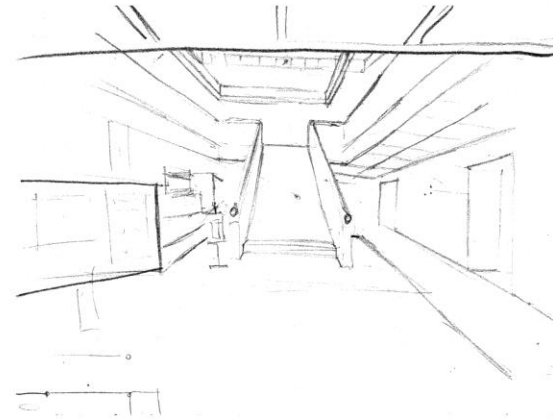
B2-L1

Figure 47 A7's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

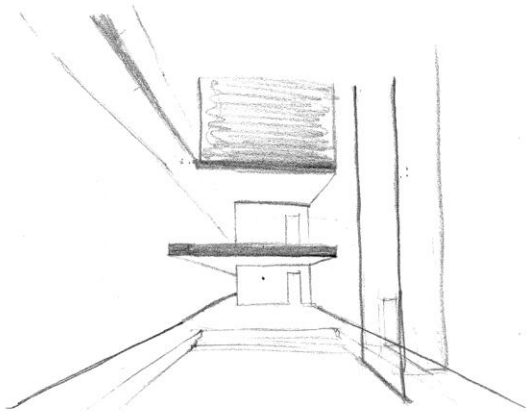
Drawings of A8



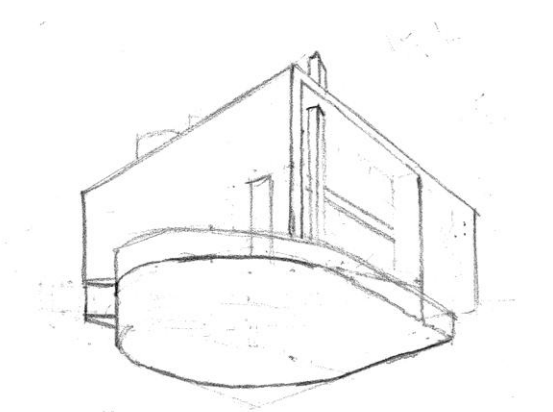
ABS



RBS



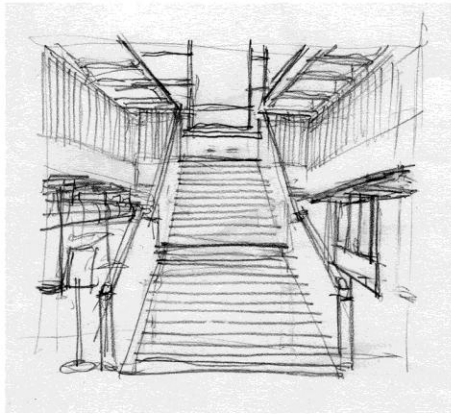
B1-L2



B2-L1

Figure 48 A8's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

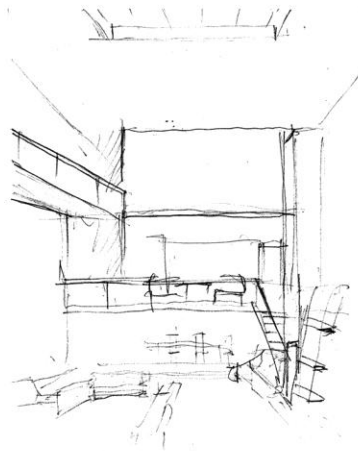
Drawings of A9



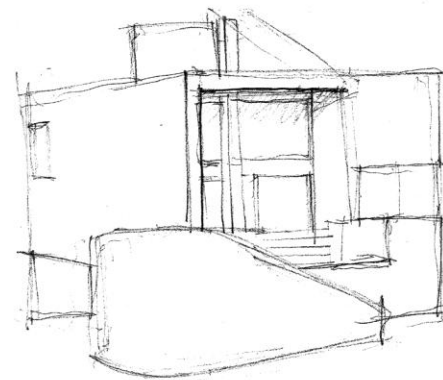
ABS



RBS



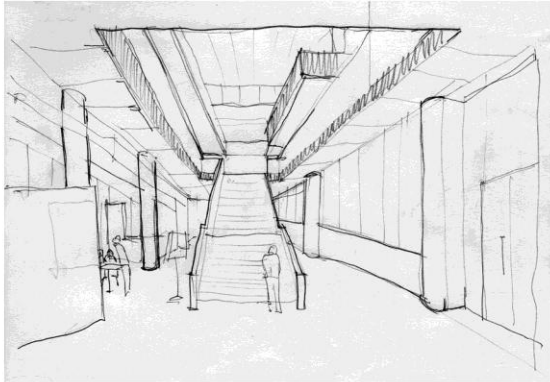
B1-L2



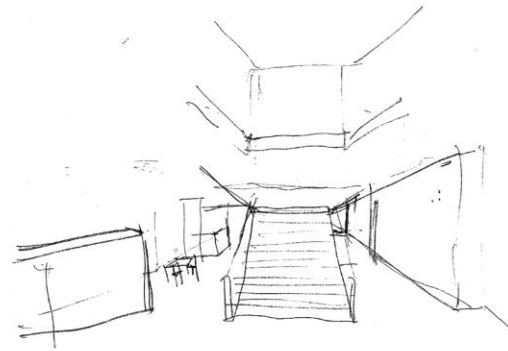
B2-L1

Figure 49 A9's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

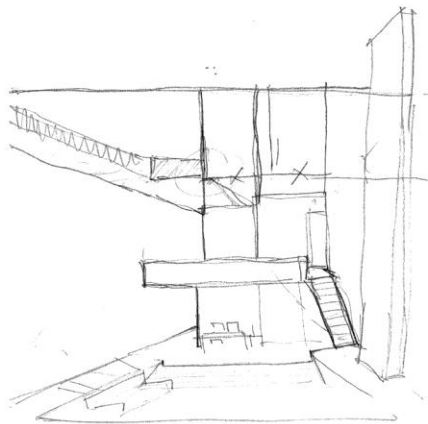
Drawings of A10



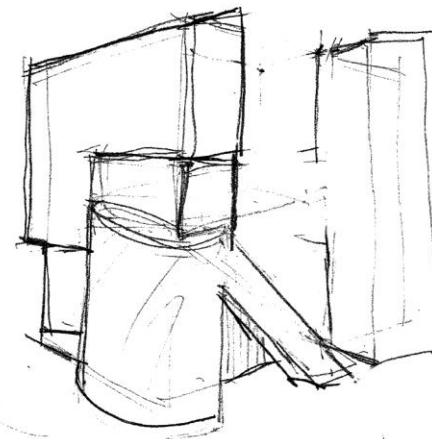
ABS



RBS



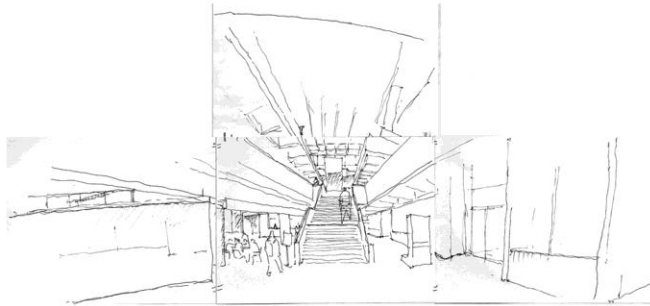
B1-L2



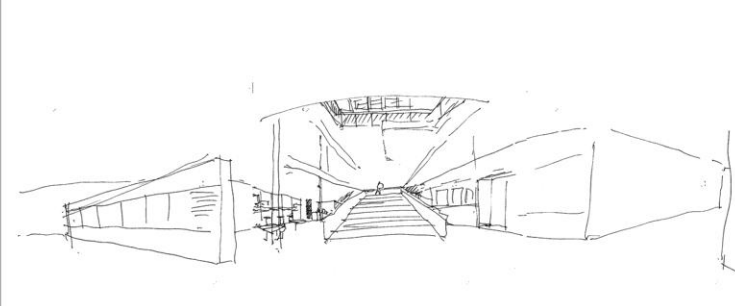
B2-L1

Figure 50 A10's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

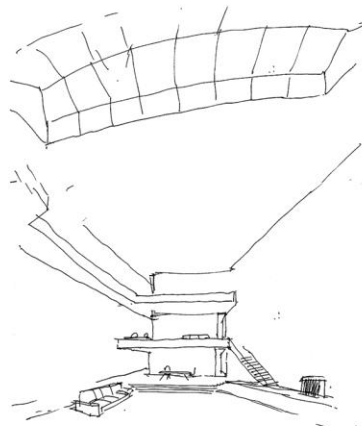
Drawings of A11



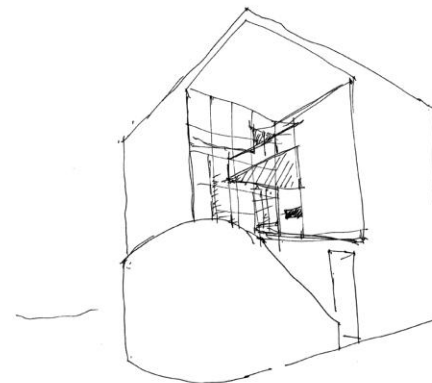
ABS



RBS



B1-L2



B2-L1

Figure 51 A11's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

Drawings of A12

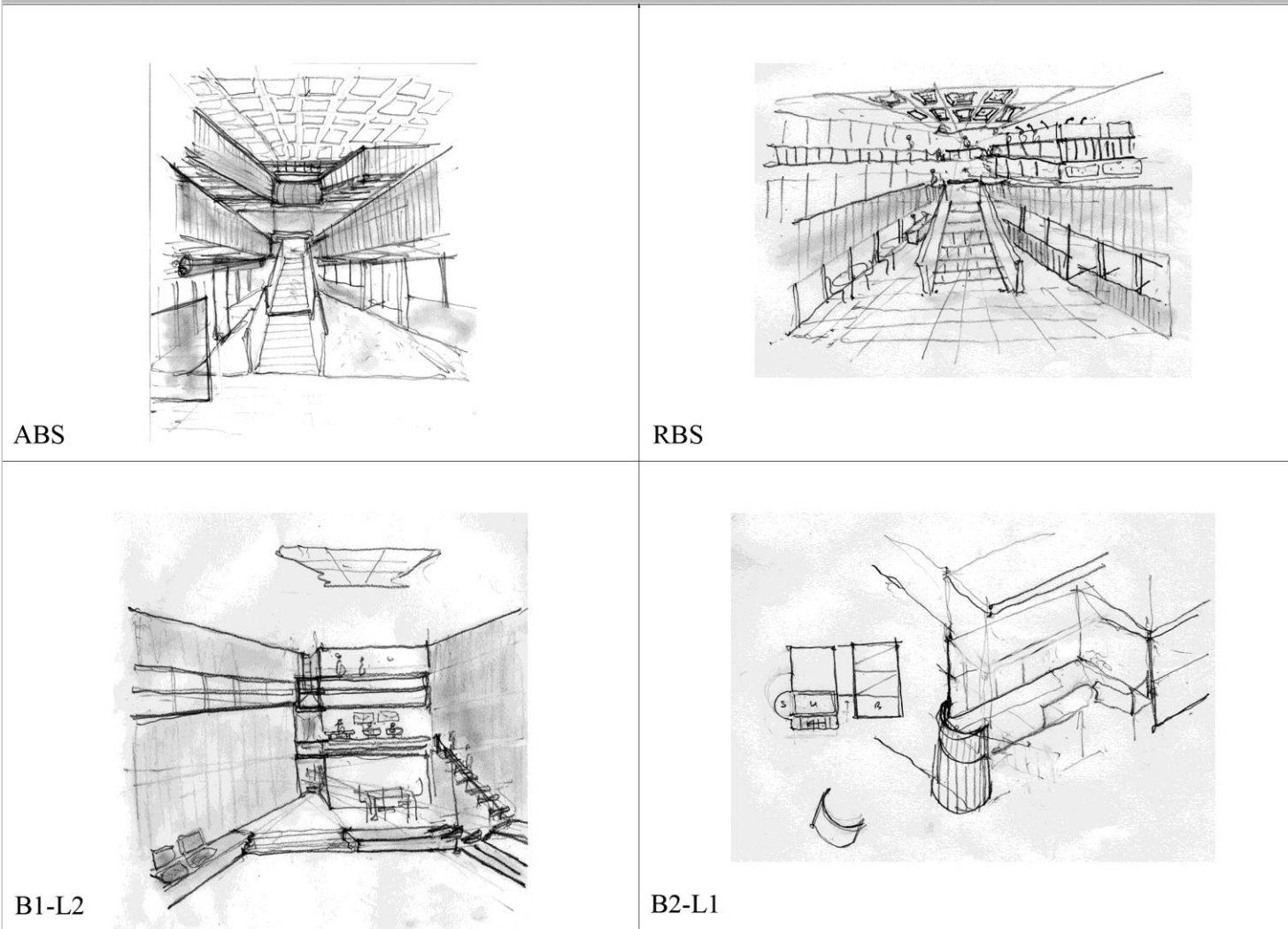
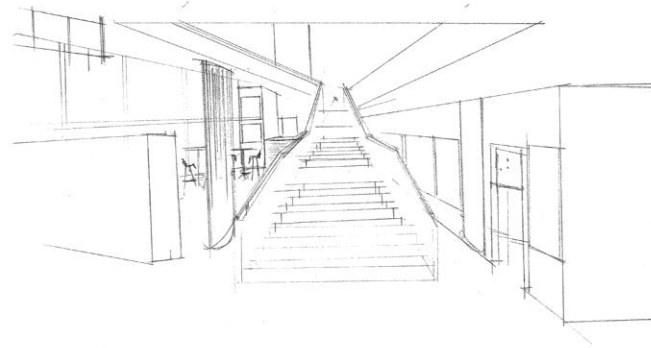


Figure 52 A12's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

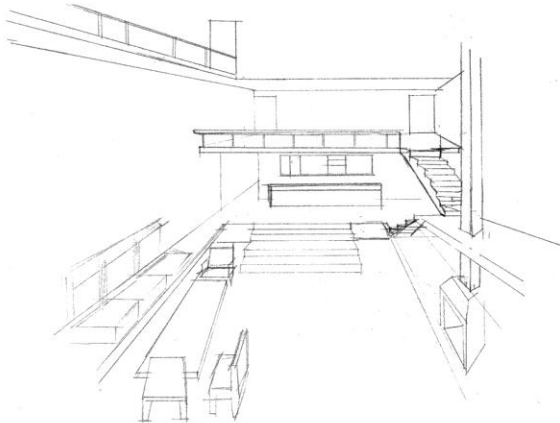
Drawings of A13



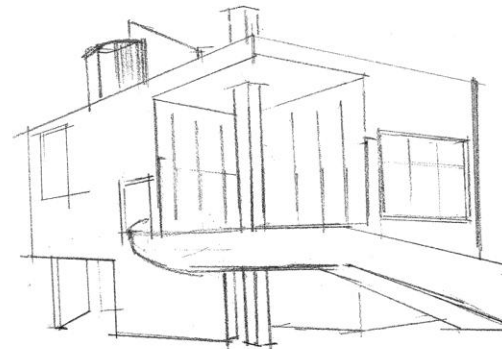
ABS



RBS



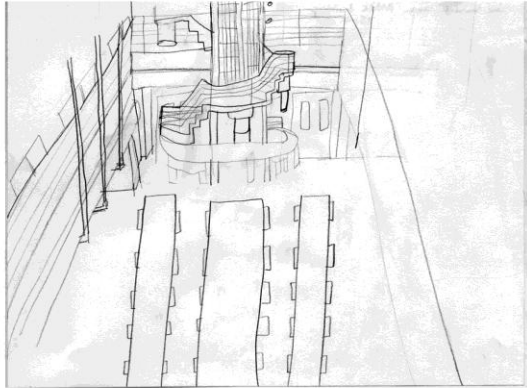
B1-L2



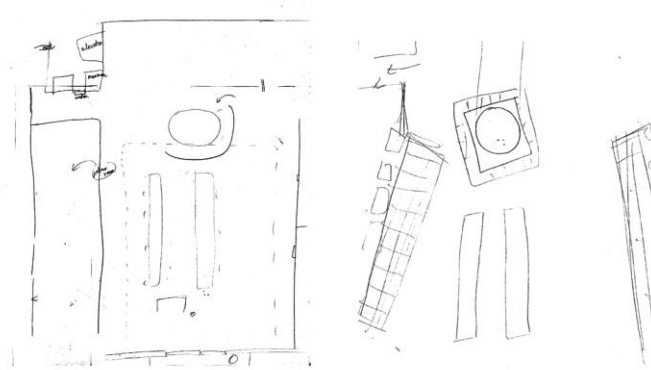
B2-L1

Figure 53 A13's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

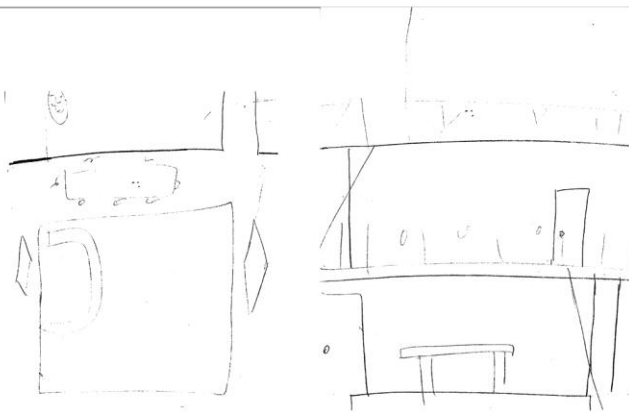
Drawings of M1



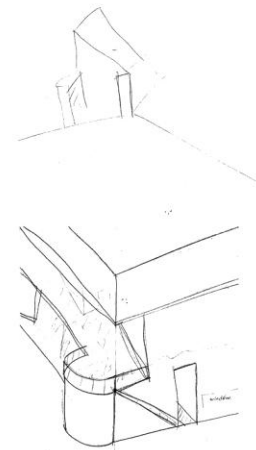
ABS



RBS



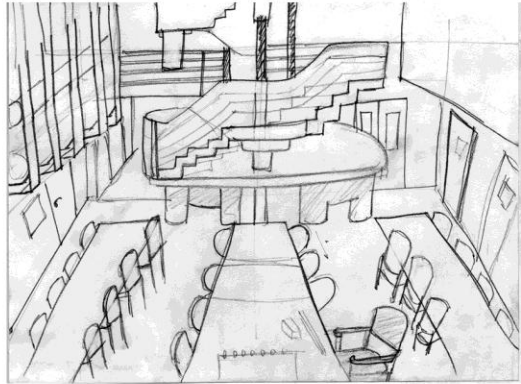
B1-L2



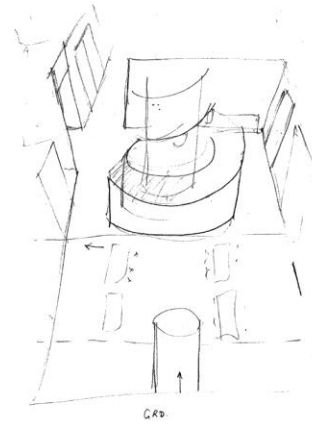
B2-L1

Figure 54 M1's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

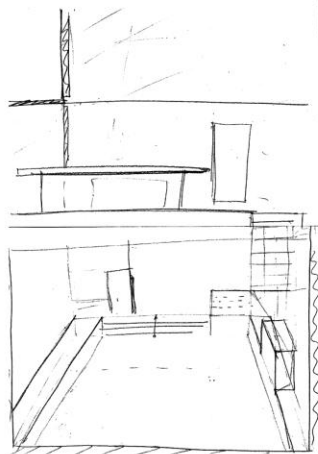
Drawings of M2



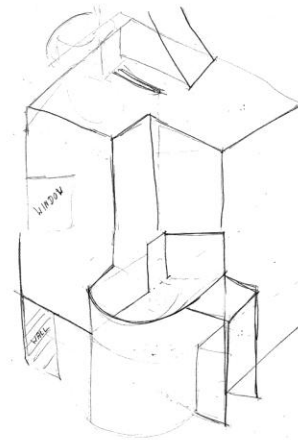
ABS



RBS



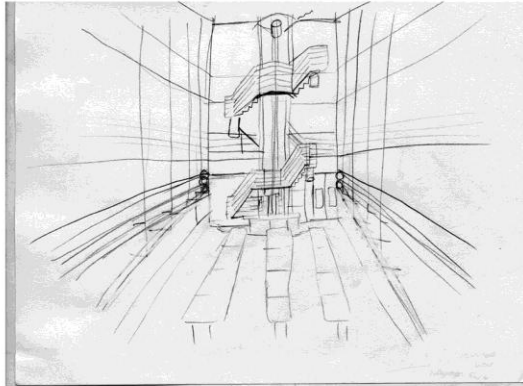
B1-L2



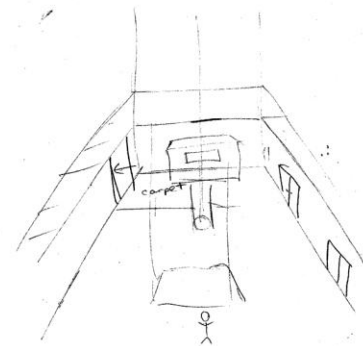
B2-L1

Figure 55 M2's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

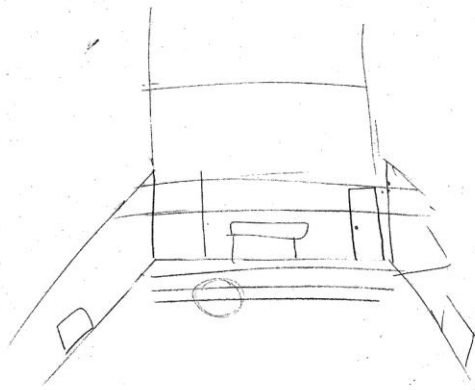
Drawings of M3



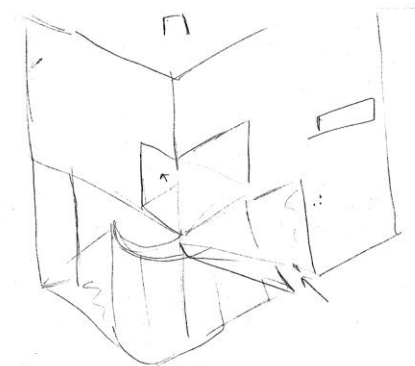
ABS



RBS



B1-L2



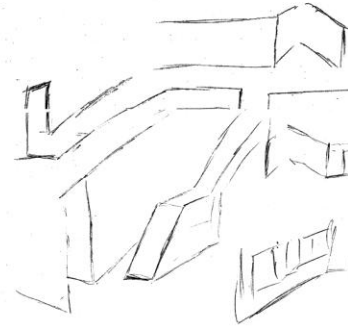
B2-L1

Figure 56 M3's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

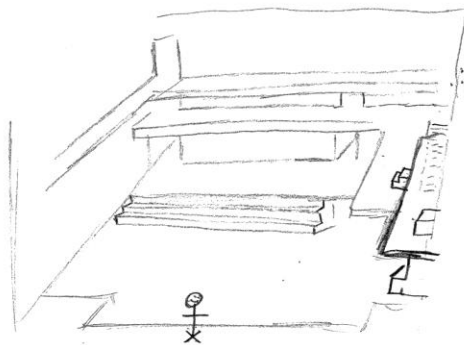
Drawings of M4



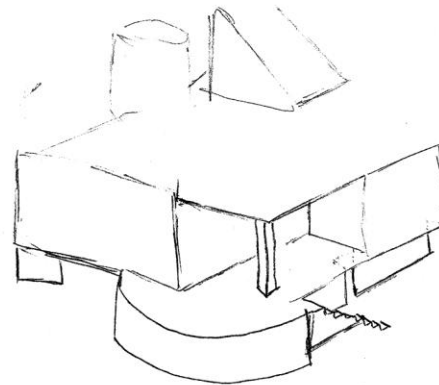
ABS



RBS



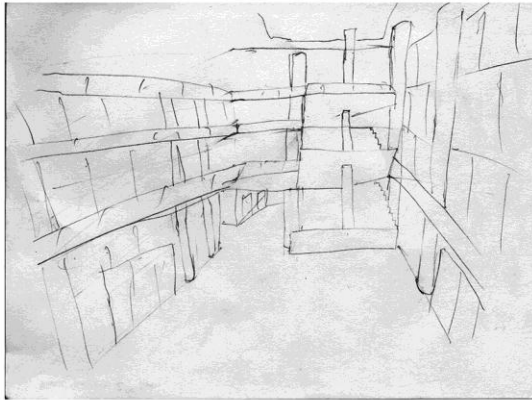
B1-L2



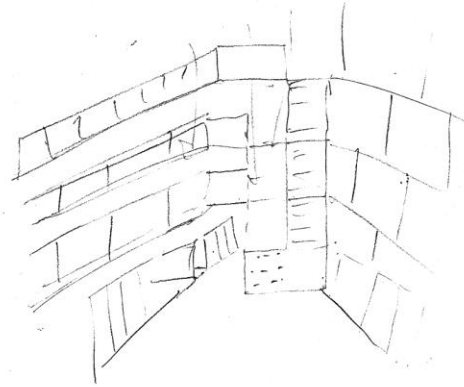
B2-L1

Figure 57 M4's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

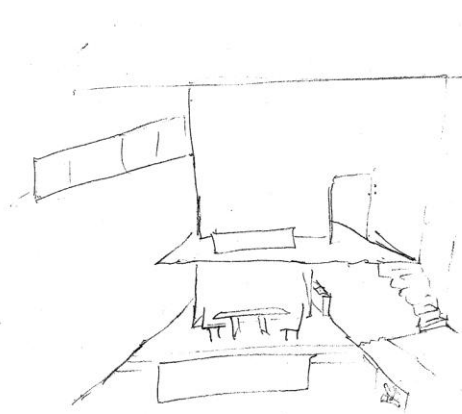
Drawings of M5



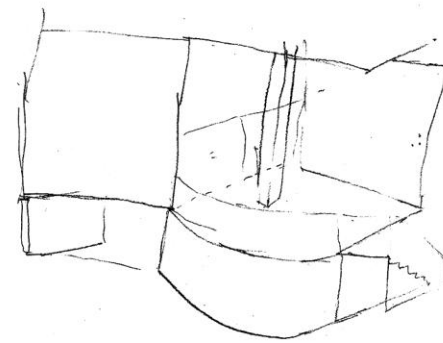
ABS



RBS



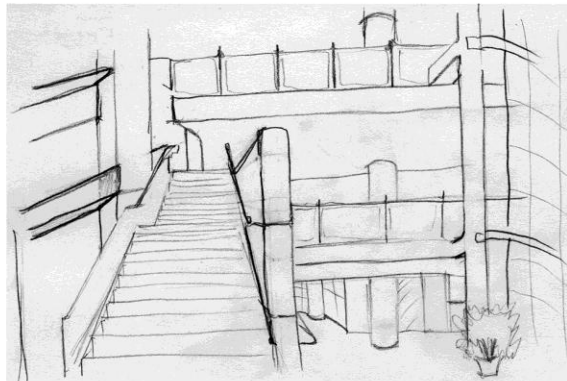
B1-L2



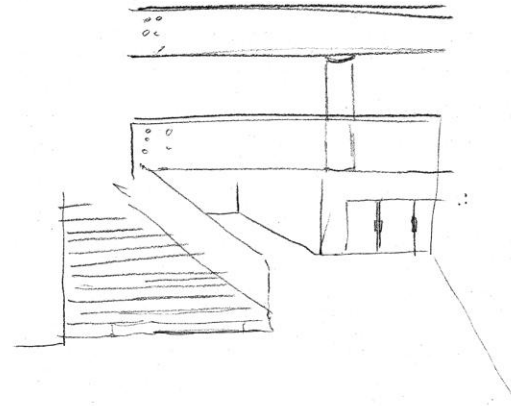
B2-L1

Figure 58 M5's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

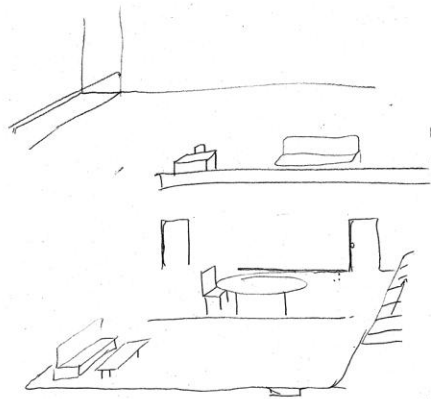
Drawings of M6



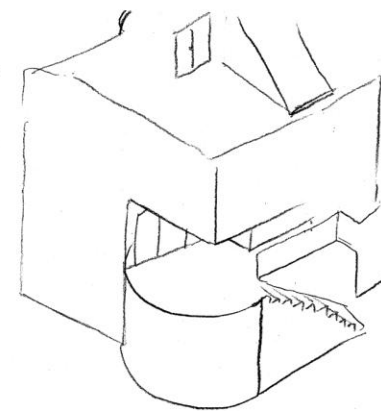
ABS



RBS



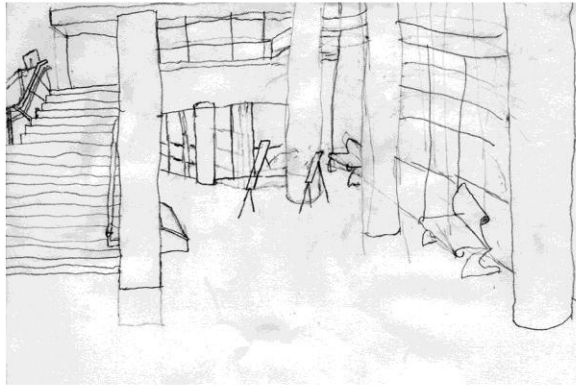
B1-L2



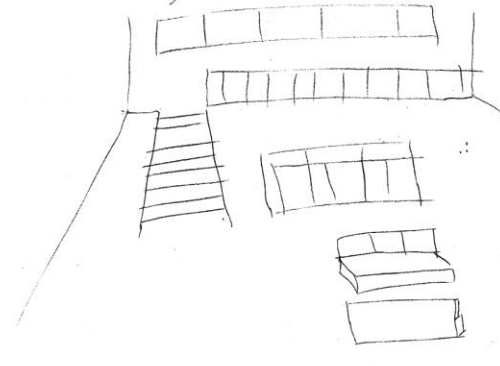
B2-L1

Figure 59 M6's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

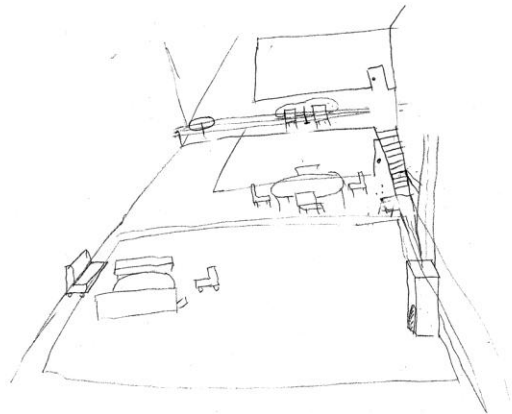
Drawings of M7



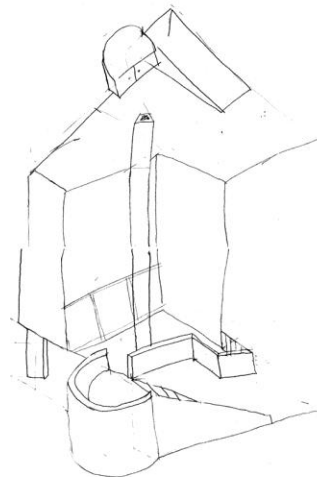
ABS



RBS



B1-L2



B2-L1

Figure 60 M7's drawings of ABS and RBS and mental visualizations of B1 and B2 from the given locations

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